Hydrology of Cornfield Wash Area and Effects of Land-Treatment Practices, Sandoval County New Mexico, 1951–60

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1831

Prepared in cooperation with the U.S. Bureau of Land Management

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By D. E. BURKHAM

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CONTENTS

	Page
Abstract	1
Introduction	2
Purpose and scope of investigation	2
Previous investigations	4
Acknowledgments	6
Description of the area	6
Location	6
Climate	6
Physiography	10
Geology and soil	13
Vegetation	14
Study procedure	14
Precipitation	14
Runoff and sediment	15
Land treatment	18
Precipitation	19
Tabulation of data	19
Magnitude and frequency	21
Runoff	23
Tabulation of data	23
Magnitude and frequency	47
Relation to precipitation	48
Relation to basin characteristics	51
Sedimentation	54
Tabulation of data	54
Relation to runoff	56
Influence of basin characteristics	56
Effects of land treatment	58
Reservoirs	58
Transit losses	58
Evaporation losses	59
Seepage losses	61
Flood control	62
Water supply	62
Sedimentation and erosion	62
Gully control	63
Vegetation	66
Wire sediment barriers	66
Range pitting	67
Runoff	67
Sediment	67
Soil moisture	67
Vegetation	68

	Page
Comparison of data from Cornfield Wash basin with data from nearby basins	71
Precipitation	71
Precipitation-runoff relation	73
Runoff-basin characteristic relation	77
Transit losses	79
Magnitude and frequency of runoff	80
Comparisons of basin characteristics	81
Land slope	82
Equivalent slope	82
Length of longest watercourse	82
References cited	85

ILLUSTRATIONS

		Page
PLATE 1.	Hydrologic map	In pocket
FIGURE 1.	Index map	7
2.	Rainfall map for Cornfield Wash basin	9
3.	Rainfall map for New Mexico	10
4.	Graph of average monthly precipitation	11
5.	Photograph of gullied channel	12
6.	Photograph of vegetation types	14
7.	Water-stage graph	17
8.	Photograph of hog-wire sediment barrier	18
9.	Graph showing relation of 3-day flood volume to size of drainage basin	48
10.	Graphs showing relation of seasonal precipitation to composite seasonal runoff	49
11.	Graph showing relation of average runoff for 1951–60 to size of drainage basin	53
12.	Graph comparing computed runoff to measured runoff	54
13.	Graph showing relation between composite seasonal runoff and composite seasonal sediment	57
14.	Graph showing relation between average seasonal sediment yield and average seasonal runoff	58
15.	Profile showing the course of reservoir filling and channel erosion	64
16.	Photographs showing spillway erosion	65
17.	Location map of portable exclosures	69
18.	Graph showing relation of average seasonal precipitation to altitude	72
19.	Graph showing relation of seasonal runoff to seasonal precipitation	76
20.	Double-mass diagram of measured runoff to synthetic runoff	77
21–25.	Graphs showing—	
	21. Relation of seasonal runoff for 1951–59 to size of drainage basin	78
	22. Relation between mean annual flood (3-day volume) and size of drainage basin	80

Page

Figure 23. Relation of land slope to size of drainage basin --- 83
24. Relation of equivalent slope to size of drainage basin --- 84
25. Relation of length of longest watercourse to size of drainage basin --- 85

TABLES

Page

Table 1. Reservoirs in Cornfield Wash --- 16
2. Precipitation in Cornfield Wash basin for warm seasons, May through October 1951–60 --- 19
3. Major storm precipitation measured at recording gage 6 --- 21
4. Storm runoff measured in reservoirs in Cornfield Wash --- 25
5. Seasonal runoff and annual sediment deposition, 1951–60 --- 44
6. Comparison of computed spill with gaged spill --- 46
7. Spillage from reservoirs in the Cornfield Wash basin --- 47
8. Average annual sediment accumulation and related hydrologic and drainage-basin data, 1951–60 --- 55
9. Seasonal stock-pond evaporation, San Luis Wash reservoir 3 --- 60
10. Annual evaporation and seepage from the reservoirs in Cornfield Wash basin, 1951–61 --- 61
11. Yields for two pitted and two untreated watersheds in the Cornfield Wash basin --- 70
12. Comparison of average precipitation, May through October 1951–60, and long-term average, May through October, at U.S. Weather Bureau stations near Cornfield Wash --- 73
13. Drainage-basin and related hydrologic data for Cornfield Wash and nearby watersheds --- 74

HYDROLOGY OF CORNFIELD WASH AREA AND EFFECTS OF LAND-TREATMENT PRACTICES, SANDOVAL COUNTY, NEW MEXICO, 1951-60

By D. E. Burkham

ABSTRACT

The collection of runoff and sediment data was the primary objective of the 10-year (1951–60) study in the Cornfield Wash basin, which has an area of 21.3 square miles. However, reconnaissance investigations also were made of (1) precipitation; (2) the effects of reservoirs on runoff, erosion, and sediment yield; (3) the effects of range pitting on runoff, sediment, and vegetation yields; and (4) the effects of wire sediment barriers on sediment accumulations.

Precipitation averaged 6.07 inches for the warm season (May 1 through October 31). From 1951 to 1955 much of the precipitation came in short torrential downpours. Since 1955, precipitation usually has been of lower intensity, resulting in a low runoff-precipitation ratio.

The total composite inflow to the 19 reservoirs in the Cornfield Wash basin—12 constructed in 1950 and 7 constructed from 1953 to 1956—was 5,720 acre-feet. The reservoirs permanently retained 1,370 acre-feet of water, 43 percent of which was apparently lost by evaporation.

The average seasonal runoff (1951–59) from the ephemeral streams of the Cornfield Wash basin and nearby watersheds can be expressed, with a high coefficient of correlation, by the equation:

$$\text{Runoff} = 29.4\ (\text{area})^{0.82}\ \text{acre-feet.}$$

This relation suggests that there is a good correlation between the size of the drainage basin and the basin characteristics that most influence travel time of runoff. Comparisons of readily measurable basin characteristics that influence travel time indicate:

1. Land slope is proportional to $(\text{area})^{-0.035}$;
2. Length of longest watercourse is proportional to $(\text{area})^{0.52}$;
3. Distance along the longest watercourse from gaging station to a point opposite the center of drainage basin is proportional to $(\text{area})^{0.52}$; and
4. Equivalent channel slope is proportional to $(\text{area})^{-0.227}$.

Except for land slope, the coefficients of correlation for each of the basin characteristics-area relations were relatively high. The correlation between seasonal runoff (1951–60) from the small watersheds of the Cornfield Wash basin and the size of the drainage basin was improved after correcting for the influence of land slope.

The original total storage capacity of the 19 reservoirs was reduced from 845 to 455 acre-feet as a result of the impoundment of 390 acre-feet of sediment. Backwater from the reservoirs influenced the deposition of an additional 20 acre-feet of sediment.

The average annual accretion of sediment (1951–60) in the reservoirs of the Cornfield Wash basin can be expressed by the equation:

Sediment $= 0.0119$ (seasonal runoff)$^{1.3}$ (incised channel density)$^{0.71}$. By removing seasonal runoff as a variable, the average annual sediment accretion is proportional to (area)$^{1.19}$ (incised channel density)$^{1.3}$.

Conservation and rehabilitation of damaged land were successful in some instances and only partly successful in others. The reservoirs are effective in inducing sediment accretion upstream; also, they stop the advance of abrupt headcuts below the reservoirs, but only as long as the spillage is not great and the spillway stays intact. In addition, the reservoirs are effective in reducing flood peaks. A longer period of study is necessary to define adequately the effectiveness of the wire sediment barriers. The data collected on range-pitting effects were not complete enough to define the magnitude of the changes, if any, in runoff, sediment, and vegetation yields.

INTRODUCTION

PURPOSE AND SCOPE OF INVESTIGATION

Erosion and sedimentation damage constitutes a serious threat to the future welfare of the West. Its cost runs into many millions of dollars annually through reduction in reservoir capacities; aggradation of river channels; choking of irrigation canals, ditches, and drains; detrimental deposition on land, crops, and in dwellings or other buildings; and water wastage through evapotranspiration from nonbeneficial vegetation growing on sediment deposits. The lands of the public domain, especially the part administered by the U.S. Bureau of Indian Affairs and the U.S. Bureau of Land Management, contribute a relatively large share of this damaging sediment (President's Water Resources Policy Comm., 1950, p. 123–140).

To reduce and control erosion, keep sediment at its source, and rehabilitate damaged land, the Bureau of Land Management and Bureau of Indian Affairs apply many improvement practices to the lands of the public domain. The most common land-improvement practices are sediment-control structures, water spreading, ripping, pitting, terracing, and vegetation modification. Little is known about the effects and the useful life of these improvement practices or the effects of these practices on local and downstream water supply.

A program of rehabilitation of damaged land was started in the Cornfield Wash basin in 1950 when the Bureau of Land Management began construction of conservation structures. These structures are part of a land-treatment program designed to reduce floodflow, alleviate erosion, stop or greatly retard headcutting of

gullies, protect Indian farmlands in the lower part of the basin, and provide a source of domestic and irrigation water for the Indians (Kennon and Peterson, 1960, p. 48). The program included construction of a series of retarding reservoirs on the main channel and some of its major tributaries. The plan was to provide sufficient storage in each of the reservoirs to retard flood runoff. By using open-pipe outlets through the dams, stored floodwater could be released at rates that would not cause serious erosion in the channel below. Additional outlet pipes in reservoirs 11 and 12 (pl. 1) were provided with valves so that a small part of the water could be reserved for irrigation and domestic use by the Indians.

In the spring of 1956 an effort was made by the Bureau of Land Management to induce sediment aggradation and thus conserve reservoir storage capacity by building a series of barriers across the channels above reservoirs 6, 7, 11, and 12. The hog-wire obstructions were designed to reduce the stream velocity and force some spread of the flow beyond the channel, thus causing the stream to drop part of its sediment load before reaching the reservoirs (Kennon and Peterson, 1960, p. 101). If proven practical, the practice could be used as a means of filling arroyos and conserving reservoir capacity.

It is obvious that arroyo-control structures, built at critical points where destructive gullying is progressing unabated, cannot correct the causes of rapid sheet erosion on adjacent uplands. Therefore, the establishment of vegetation to reduce sheet erosion becomes a major part of the rehabilitation and preservation of a watershed. In 1956, in an attempt to improve infiltration and thus accelerate growth of vegetation, much of the Cornfield Wash basin was treated with a Calkins spike-tooth pitter. The spikes of the pitter penetrate the soil surface to depths of as much as 15 inches and leave holes about 5–6 inches in diameter arranged in a grid pattern on 3-foot centers. The depths of penetration depend largely on the hardness of the soil.

Data on flood magnitude and frequencies and sediment yield are very scarce for basins of less than 50 square miles in the arid and semiarid regions of the United States; therefore, the design of structures in the Cornfield Wash basin was based on estimates or, more correctly, "guesses" of expected floods and sediment yield. The success of the conservation structures depends, among other things, on how adequately the "guesses" can define the actual runoff and sediment yield.

The Cornfield Wash basin was selected for study because it is

219-285 O—66——2

representative of the badly eroded lands of the upper Rio Puerco basin and other nearby watersheds. Also, conservation reservoirs in the Cornfield Wash basin provide a relatively inexpensive means by which data on runoff and sediment yield may be collected. If reasonably good records can be obtained, they will provide guidance for the design of conservation structures in other basins of less than 50 square miles.

A 10-year program directed primarily toward the collection of runoff and sediment-yield data was started by the U.S. Geological Survey in cooperation with the U.S. Bureau of Land Management in the Cornfield Wash basin in 1951. Investigations of a reconnaissance nature were initiated, as the opportunities arose, to determine (1) precipitation; (2) the effects of reservoirs on runoff, erosion, and sediment yields; (3) the effects of range pitting on runoff, sediment, and vegetation yields; and (4) the effects of wire sediment barriers. Precipitation data, although not a primary objective, were collected at one place during the early phase of the study, and precipitation records were obtained at several sites during the succeeding years. Kennon and Peterson (1960) summarized the data on precipitation, runoff, and sediment yield obtained in the 5-year period 1951–55. This report presents the findings of the entire 10-year period (1951–60).

The investigations in the Cornfield Wash area are part of a program involving data collection and hydrologic research on lands of the public domain. The results can be used for the design of more effective land-treatment methods. The Cornfield Wash area is one of several localities where studies of this type are being made under the soil and moisture conservation operation program of the Geological Survey.

The study began in 1951 under the supervision of H. V. Peterson, project hydrologist, and was completed in 1960 under the supervision of K. R. Melin, chief, Soil and Moisture Conservation Program, U.S. Geological Survey. Those who assisted in the study were C. T. Snyder, geologist, and R. C. Culler, hydraulic engineer, 1951; F. W. Kennon, hydraulic engineer, 1952–58; and D. E. Burkham, hydraulic engineer, 1959–60. Studies of vegetation as affected by range pitting were made by F. A. Branson, botanist, 1958–60.

PREVIOUS INVESTIGATIONS

Many reconnaissance-type studies have been made of the area including Cornfield Wash. Dutton (1885, p. 125) stated that the climate probably was moist in late Eocene and Miocene time and that the area was once at about sea level. Dutton infers that if

the present climate in New Mexico were moist, the arroyos of the Rio Puerco watershed would be equal in depth to the Grand Canyon. Gardner (1910) examined the area in 1908 in a search for coal. His reconnaissance map shows the Cornfield Wash basin as being underlain by the Mesaverde Formation and Lewis Shale, but further details on the characteristics of the rocks were not reported because the basin contained no commercial coal veins. Darton (1922) examined the area in a search for oil and gas accumulation. He mentioned only the low dip of the rocks in the vicinity. These reconnaissance reports discuss erosion only in a general way.

Bryan (1928, p. 265–282), on the basis of historical evidence, stated that the severe erosion in the Rio Puerco watershed probably had its modern beginning between 1885 and 1890. These dates coincide with those in which large numbers of livestock were introduced into the area. Bryan concluded that overgrazing inaugurated the current destructive erosion cycle but that the ultimate cause is related to cyclic fluctuations in climate.

Leopold (1943, 1951) and Thornthwaite and others (1942) studied the precipitation and vegetation of the Southwest and have, in general, supported Bryan's thesis that overgrazing merely hastened the start of severe erosion and that the ultimate cause is related to cyclic fluctuation in climate.

Thornthwaite and others (1942, p. 127) stated that "owing to the delicate adjustment of vegetation to climate in the Southwest, a succession of even a few dry years may so impoverish the plant cover that rains of heavy, or even moderate, intensity can initiate a period of accelerated erosion."

Leopold (1951, p. 305) concluded that—

> It was not until 1885 or 1890 that the arroyo of the Rio Puerco began its main deepening and widening. Judging from the presence of large discontinuous gullies in 1850 and the fact that the vegetative cover, even on the valley floor, was not uniformly good, it might logically be surmised that even before 1850, climatic factors had already initiated a tendency toward decreased vegetation and thus had caused active alluviation to cease. A high degree of instability of the valley alluvium probably characterized the period when the first exploring parties described the Rio Puerco. The later introduction of heavy grazing was promptly followed by more extensive erosion.

Calkins (1941) believed that Bryan overemphasized the role of climate in causing the serious erosion that developed after 1880.

Recent studies by Leopold and Maddock (1953), Leopold and Miller (1956), and Schumm (1960) have increased the understanding of the hydraulic characteristics of gullies and arroyos and have shed new light on the interrelations that exist between drainage

nets, hydraulic and hydrologic factors, and the geometry of natural stream channels.

Rangeland conservation and rehabilitation in the Rio Puerco area began in the 1930's under the auspices of the Works Progress Administration. Conservation work has continued since then with a varying degree of effort. The Cornfield Wash study is the first attempt to determine the effects and adequacies of these conservation measures.

ACKNOWLEDGMENTS

The cooperation of personnel of the U.S. Bureau of Land Management in assisting with the observations, maintaining the structures, and otherwise facilitating the study is hereby gratefully acknowledged. The enthusiastic support and interest in the study by E. R. Smith, formerly State supervisor; D. I. Bailey, range and forestry officer; and H. W. Pearson, State range conservationist, all of the Bureau of Land Management, Santa Fe, N. Mex., have been particularly valuable. The author gratefully acknowledges the advice and assistance given by R. F. Hadley, S. A. Schumm, R. F. Miller, and G. G. Parker, all of the U.S. Geological Survey. Constructive suggestions and comments on conducting the program have been received from many persons in other agencies who visited and inspected the area and maintained interest in the progress of the study.

DESCRIPTION OF THE AREA

LOCATION

The Cornfield Wash basin has an area of 21.3 [1] square miles and is about 55 miles northwest of Albuquerque near the small setttlements of Cuba and San Luis in Sandoval County, N. Mex. (fig. 1). The average altitude is about 6,500 feet above mean sea level. Cornfield Wash is a tributary of the Rio Grande by way of Arroyo Torreon and Chico Arroyo and the Rio Puerco. It is representative of the upper Rio Puerco basin, an area of excessive erosion and high sediment yield. The basin, which is used mainly for grazing, is in districts 1 and 7 of the federally owned lands administered by the Bureau of Land Management.

CLIMATE

The maximum and minimum temperatures in the Cornfield Wash basin, similar to most arid and semiarid areas of the Southwest, vary greatly. According to the U.S. Weather Bureau, Cuba has

[1] Kennon and Peterson (1960) reported the area of the basin to be 22.9 square miles. U.S. Geological Survey preliminary topographic maps, available after 1960, show the area to be 21.3 square miles.

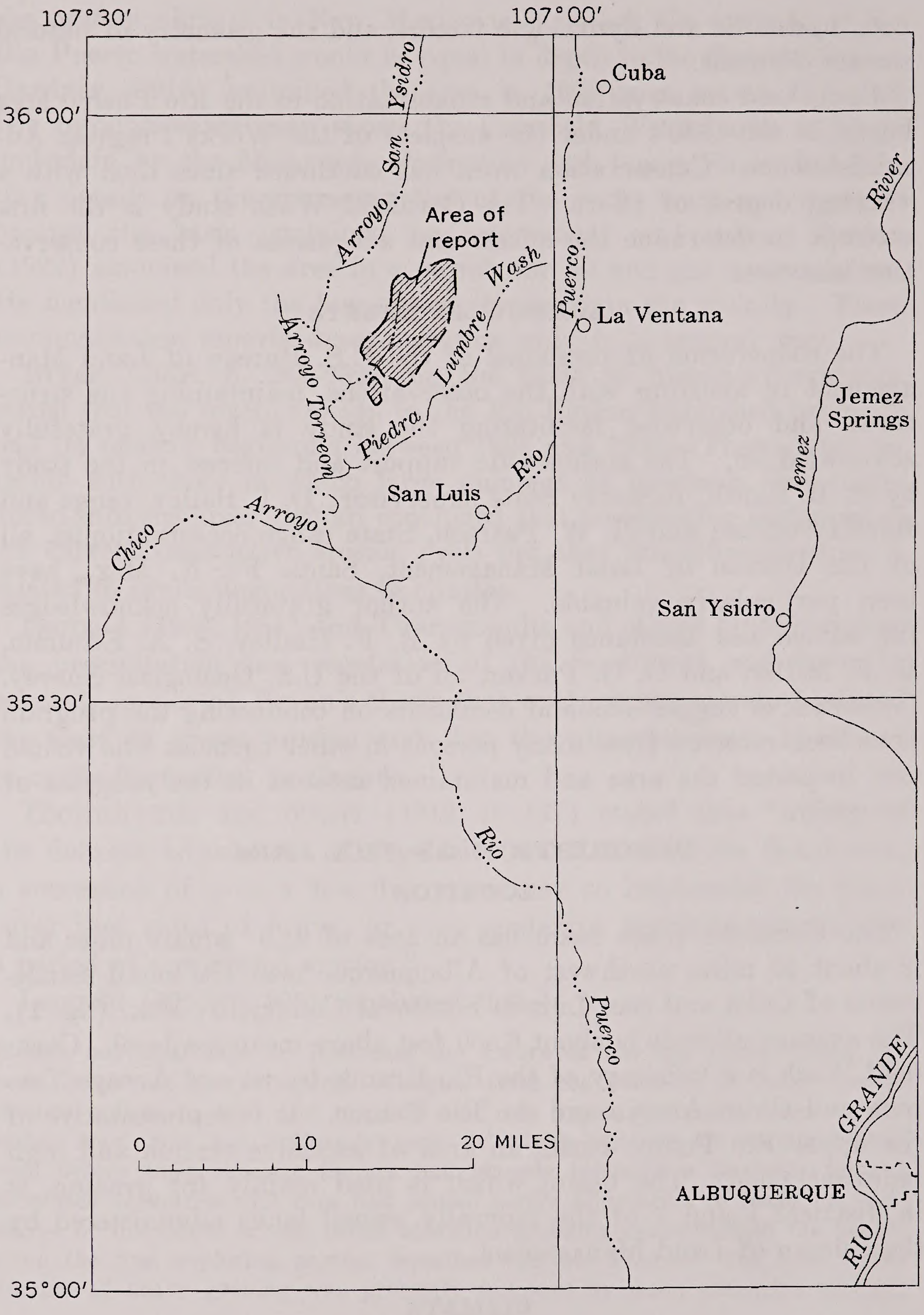

FIGURE 1.—Index map of Cornfield Wash area.

a maximum recorded temperature of 102°F and a minimum of −40°F; the mean maximum summer temperatures (May through September) range from 70° to 85°F, and the mean minimum monthly summer temperatures range from 35° to 50°F. Cuba is

about 18 miles north of Cornfield Wash and is about 6,900 feet above mean sea level or about 400 feet higher than the Cornfield Wash basin.

Precipitation in the Cornfield Wash area occurs in storms of two types. Storms in July, August, and early September are mainly of the local convective type; whereas those in the spring, fall, and winter are mainly of the convergence or frontal types.

The local convective storm, or thunderstorm as it is most commonly called, is characterized by rainfall of high intensity and short duration over a limited area. Although such rainfall may occur at many places on a given day, there is little conformity either in the rate or amount that may fall at two different places because very localized atmospheric and topographic conditions are the predominating factors involved (Dorroh, 1946). A typical precipitation pattern of a thunderstorm in the Cornfield Wash area is shown in figure 2.

Thunderstorms usually do not produce rains of a general nature, nor do they usually produce high rates of discharge from large watersheds. However, for watersheds the size of Cornfield Wash and smaller, they are predominantly the cause of peak rates of discharge.

Although thunderstorms are mainly a summer phenomenon, they may occur at other times of the year. As heating of the air near the ground level is the main cause of convective action, thunderstorm occurrence decreases in cold weather.

Convergence storms are atmospheric disturbances of a general nature and distribute much moisture over large areas. Such storms may occur when air masses of dissimilar characteristics meet or override one another or when warm air converges toward a center and is forced upward (Dorroh, 1946). A typical precipitation pattern of a convergence storm is shown in figure 3.

Although thunderstorms occur mainly in the summer and frontal storms develop primarily in the spring, fall, and winter, it is not uncommon to have thunderstorm activity during frontal storms. The relatively low-intensity rainfall of general coverage associated with frontal storms and the high rainfall of localized convective action produce large floods.

The average annual precipitation for the area is about 11 inches. The average monthly precipitation at Johnson Trading Post, about 1 mile north of the Cornfield Wash basin and at a slightly higher altitude, is shown by bar graphs in figure 4. About 50 percent of the annual precipitation falls in July, August, September, and October. The winter precipitation of gentle-intensity rain and

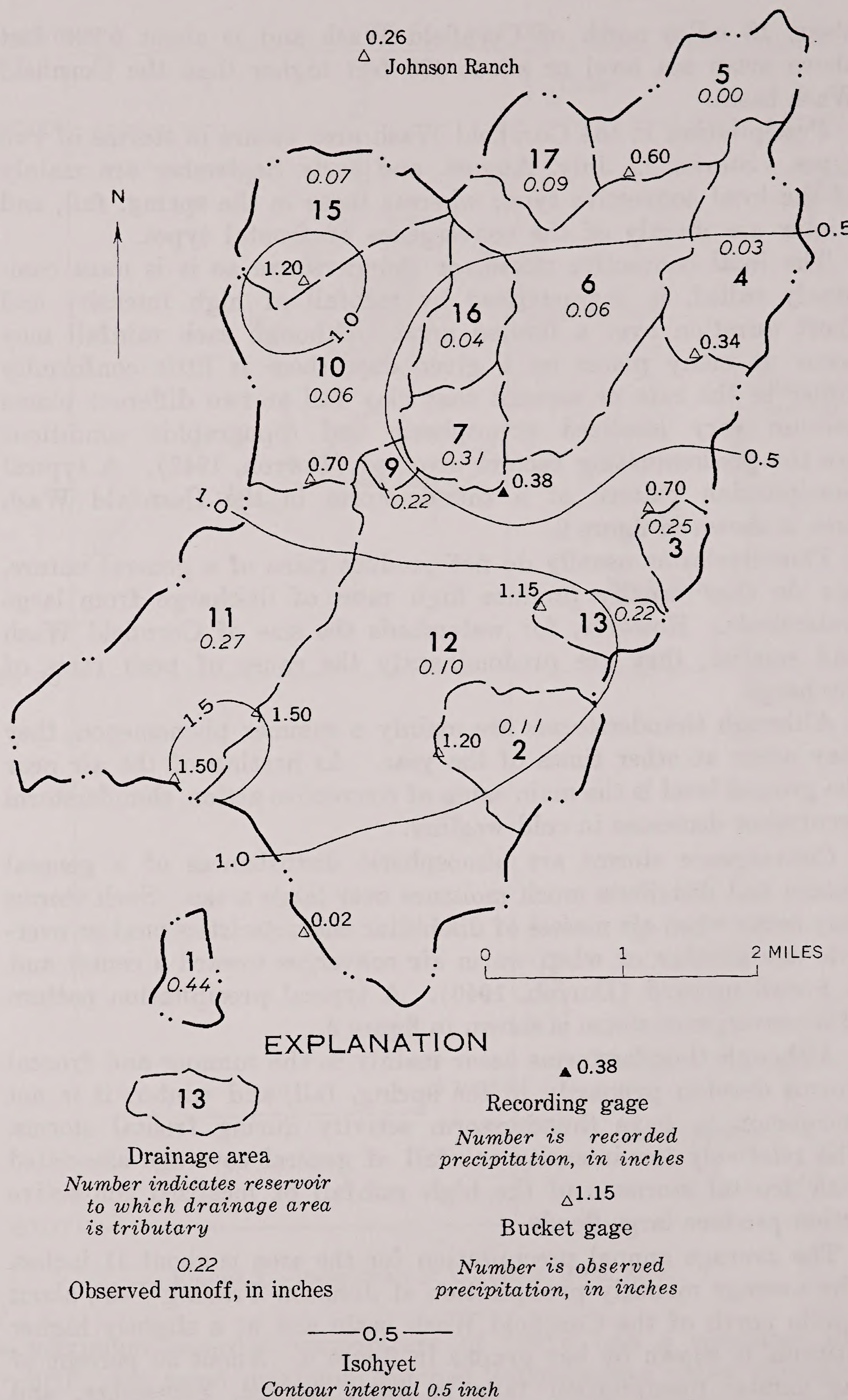

FIGURE 2.—Rainfall map for Cornfield Wash basin, August 18–24, 1955.

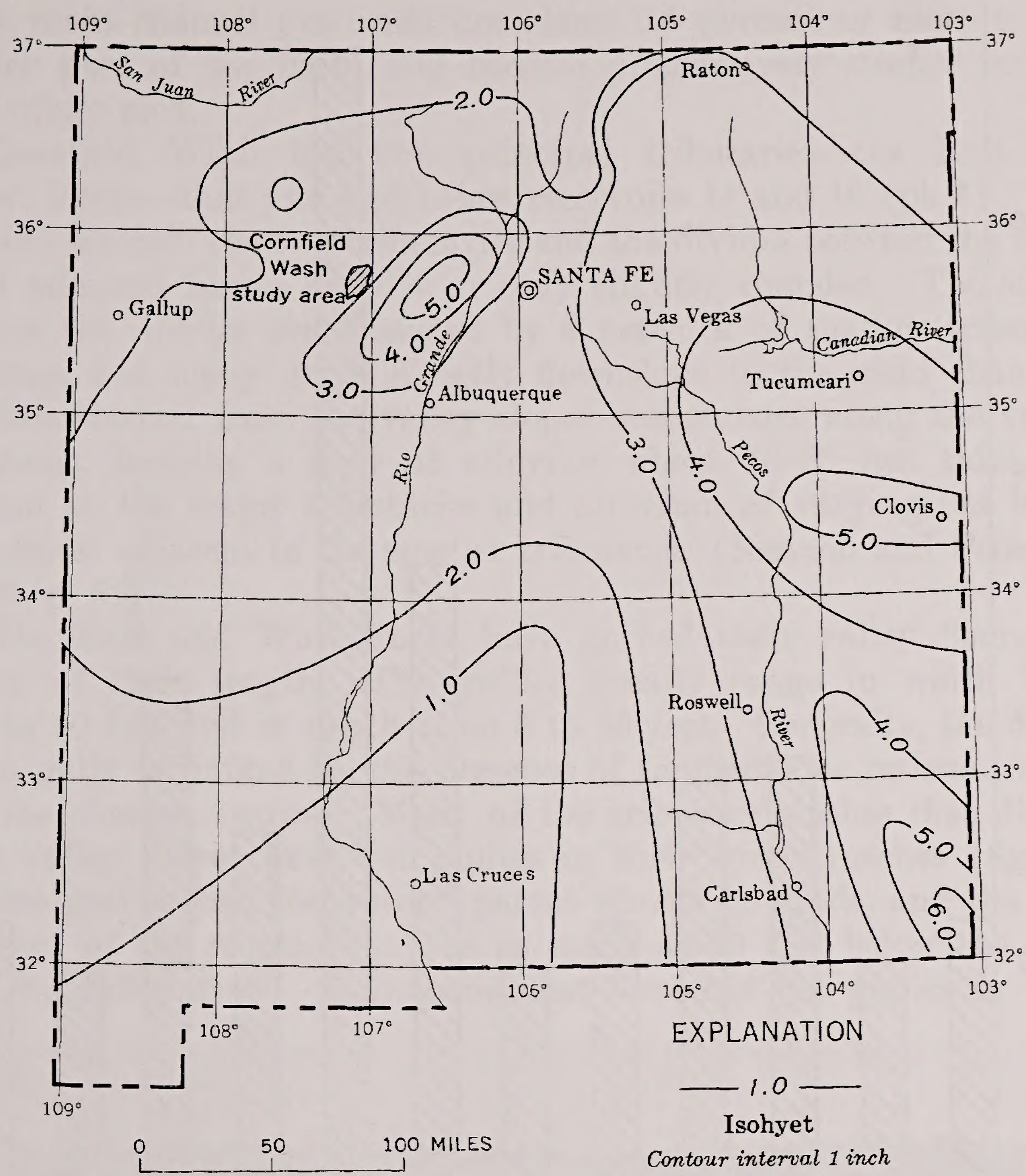

FIGURE 3.—Rainfall map for New Mexico, October 15–19, 1960.

snow seldom, if ever, produces runoff at altitudes below 6,500 feet (Kennon and Peterson, 1960, p. 50).

PHYSIOGRAPHY

Cornfield Wash is in the Navajo section of the Colorado Plateaus physiographic province as described by Fenneman (1931). Similar to other parts of the Colorado Plateaus province, the Cornfield Wash area is characterized by horizontal or only slightly inclined rock strata, relatively high altitudes, low precipitation, and scant vegetation. The area, however, does not have the deep canyons that are common in some other parts of the province. The terrain within and surrounding Cornfield Wash is, in effect, a plateau intricately dissected by streams that have eroded moderately steep-sided shallow valleys and swales. The divides are narrow elongated mesas capped by resistant thin sandstone beds, which, in places, have the appear-

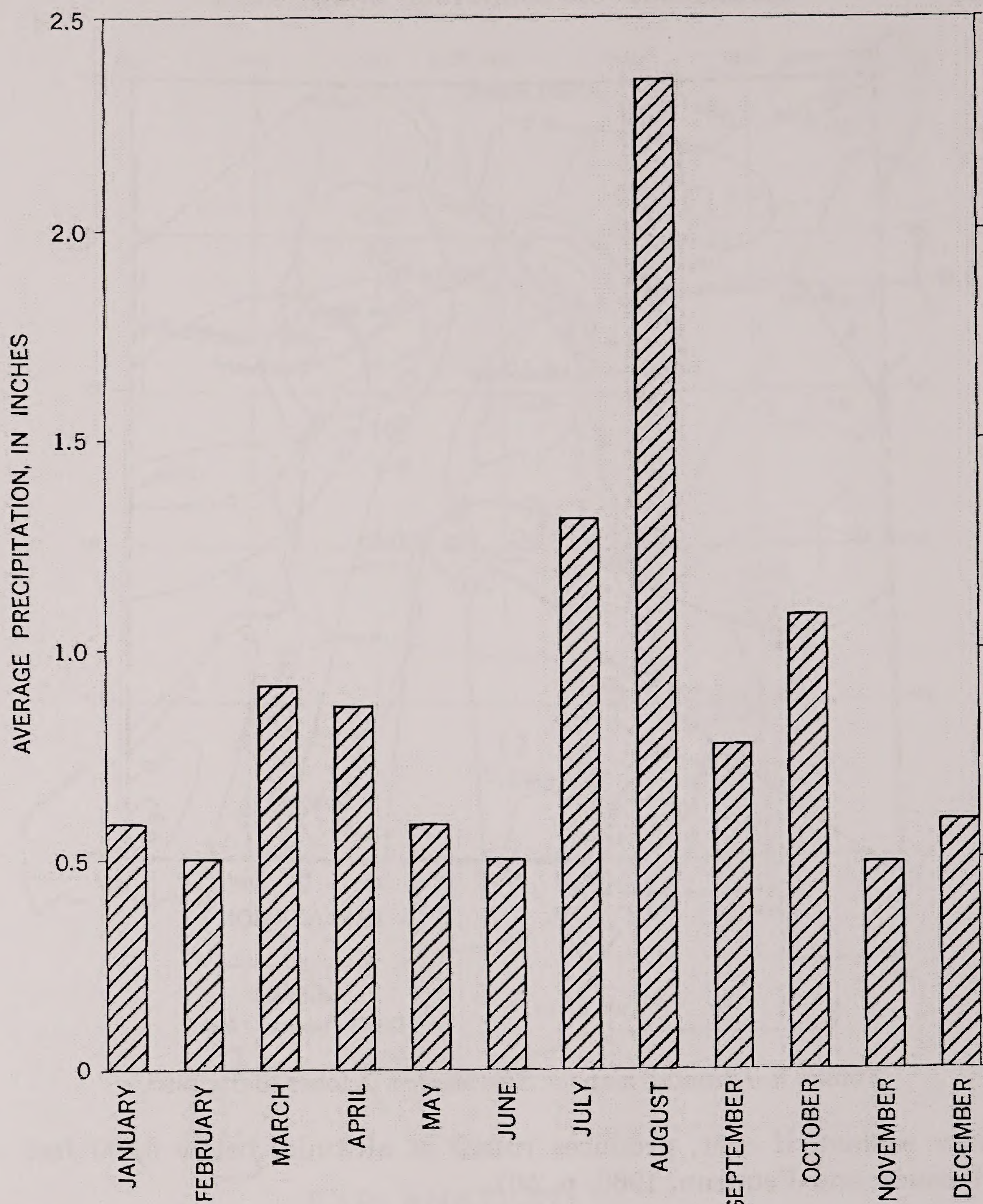

FIGURE 4.—Average monthly precipitation at Johnson Trading Post (1944–60).

ance of red sinter or scoria as a result of the natural burning of underlying coal seams; the valleys are shallow troughs cut in the softer, less resistant, underlying shale (Kennon and Peterson, 1960, p. 51).

The altitude of the basin as determined from U.S. Geological Survey preliminary topographic maps ranges from 6,440 feet on the low end of the valley floor to about 7,040 feet on the drainage divides. Slopes of valley sides range from 0.4 percent along the lower parts to about 15 percent near the summits of the divide.

219–285 O—66——3

The main channel gradients are about 0.4 percent or more in the lower part of the basin and become progressively steeper toward the upper part.

Cornfield Wash has two principal tributaries—the East and West Forks—that join just below reservoirs 11 and 12 (pl. 1). The divide between the two tributaries and the divides between the basin and adjacent basins are flat or only slightly rounded. The slopes below the divides are dissected by a network of shallow tributary washes, and many drain directly downslope to the main channels. Debris washed from the valley slopes accumulates along the valley bottoms, forming a floor of alluvium about 10–30 feet thick adjacent to the major tributaries and alluvium of varying but lesser thickness adjacent to the smaller tributaries (Kennon and Peterson, 1960, p. 51).

The East and West Forks have gullied their valley floors for most of their length. The gullies usually range in width from 20 to 50 feet and in depth from 5 to 25 feet. Generally, the depth of a gully is limited by the presence of sandstone or resistant shale in the channel bottom. Many of the tributary washes that dissect the valley slopes have cut gullies in their lower reaches (fig. 5). These gullies join the gullied parent stream at grade, and the confluence of the streams may be as much as 20 feet below the level of the valley floor. Tributaries that have not cut gullies in their

FIGURE 5.—Gullied channel below reservoir 4. Photograph by R. C. Culler, 1951.

lower reaches are graded to the valley floor, and most of the sediment carried by floodflows is deposited on the valley floor as alluvial fans, unless the flows are large enough to extend across the fans and spill into the main channel (Kennon and Peterson, 1960, p. 51–52).

GEOLOGY AND SOIL

The Lewis Shale, which underlies most of the area, is a fairly uniform thin-bedded moderately indurated drab or gray marine shale containing scattered thin lenticular beds of sandstone (Cross and Spencer, 1899). The shale forms slopes of uniform gradient, and the sandstone layers generally cap elongated mesas or ridges of varying size. The undifferentiated Allison and Gibson Coal Members were considered members of the Mesaverde Formation by Dane (1936), but they have since (Beaumont and others, 1956) been reassigned. The Allison is now a member of the Menefee Formation, and the Gibson is a member of the Crevasse Canyon Formation. The two formations are part of the Mesaverde Group. The Mesaverde underlies the Lewis Shale and contains more sandstone than the shale; consequently, the eroded slopes developed on these members are somewhat steeper than those in other parts of the basin where the coal members are absent (Kennon and Peterson, 1960, p. 52).

Soil developed on the shale consists of a thin mantle of disintegrated bedrock, mainly devoid of organic matter. There is little evidence of a soil profile, and the soil generally grades from a mixture of clay and silt at the surface to the parent rock at a depth of 2–3 feet. The clay is bentonitic and usually exhibits distinct swelling and dispersion when wetted, resulting in low infiltration rates and rapid runoff. In contrast, the sandstone mesas have sandy soil with a high infiltration rate. The general sparsity of drainage channels on the sandstone mesas indicates that there is little runoff (Kennon and Peterson, 1960, p. 52).

The valleys along the two principal stream channels and their larger tributaries are underlain by alluvial deposits as much as 30 feet thick. The alluvium consists mainly of silt and clay with scattered lenses and stringers of sandy material. Prior to gullying, the alluvial valley floors produced the best forage in the area, presumably due to the additional water they received by overflow from the channels. After the channels were gullied, the valley floors no longer received flood overflow, and, in addition, the alluvial deposits were drained at least as deep as the new channels. The present (1960) productivity of the valley alluvium, therefore, is no greater than that of other parts of the Cornfield Wash basin (Kennon and Peterson, 1960, p. 52).

VEGETATION

In general, the Cornfield Wash basin is a grassland with scattered trees occupying the ridges (fig. 6). The most prevalent species present is the introduced Russian-thistle (*Salsola kali*) (table 11). The most abundant grasses are galleta (*Hilaria jamesii*), blue grama (*Bouteloua gracilis*), and ring muhly (*Muhlenbergia torreyi*). Scattered stunted juniper (*Juniperus monosperma*) and piñon (*Pinus edulis*) are present on ridge tops and slopes underlain by sandstone. Big sagebrush (*Artemisia tridentata*) is present on sandy soils of the upper parts of the basin, and generally grasses also are most abundant on the sandy soils. Only grasses and annual weeds are present on the shale-derived and alluvial soils. Where the alluvial soils are not extensively rilled or gullied, a sparse stand of alkali sacaton (*Sporobolus airoides*) occurs; but with increased trenching and reduced flooding, the soil is barren or occupied only by annual weeds. Sheep or cattle graze in all the basin.

STUDY PROCEDURE

PRECIPITATION

Precipitation data were considered of secondary importance at the beginning of the study, and the primary objective was to obtain data on runoff and sediment; thus, few precipitation records were obtained during the early phase of the study (Kennon and Peter-

FIGURE 6.—Vegetation types found generally in the basin. The grass cover in the foreground is mainly galleta (*Hilaria jamesii*). Trees on the sandstone-capped ridges are one-seed juniper (*Juniperus monosperma*) and piñon (*Pinus edulis*). The shrub in the background is fourwing saltbush (*Atriplex canescens*). Photograph taken at watershed 7 by F. A. Branson, 1959.

son, 1960, p. 60). When it was recognized that additional precipitation records were needed, more gages were added. With the exception of 1956, enough gages were in operation after 1954 to give fairly complete areal coverage of the area.

The gages used to determine average precipitation are listed in table 2, and their locations are shown on plate 1. Charts were incomplete for parts of 1952, 1955, 1956, and 1957. The recording gage was not in operation in 1953 and 1958. Another improvised recording gage that proved to be more reliable was installed at site 6 in 1959. In 1953 a tipping-bucket gage was attached to the water-stage recorder at reservoir 2, but it also failed to operate properly at times. Three weighing-type recording gages were installed in 1956 at sites 7–9. Nonrecording bucket gages were used at the remaining sites. These gages occasionally were tipped over by livestock or destroyed by vandals, and a full season of precipitation was seldom recorded at any of the bucket gages. The catch in the precipitation gages was measured at about weekly intervals. Oil was used to retard evaporation.

RUNOFF AND SEDIMENT

The reservoirs in the Cornfield Wash basin were used in measuring runoff and sediment yield. Data on the reservoirs in the Cornfield Wash basin are shown in table 1. The small diversion reservoir and spreading areas below reservoir 7 were not used for observations (pl. 1). Outflow from reservoirs 6 and 7 drained through the spreader system and back into the channel of East Fork; loss of water in the spreader system was disregarded. The spreading area is included as part of the drainage area above reservoir 12.

The borrow pits at all reservoirs are just above the dams, except at reservoir 15 where the borrow pit is just below the dam. The borrow pits are used to store water for stock. Reservoirs 2, 5, 6, 7, 10, 11, 12, 15–17, and 20 are retarding types and have ungated outlet pipes. Reservoir 1 has a gated outlet pipe, and the remaining reservoirs do not have pipe outlets.

In those reservoirs with open-pipe outlets, the pipes generally are set near the bottom of the dam and are designed to empty the reservoir within 72 hours. In reservoirs 11 and 12, the open pipes were set higher than in the other reservoirs so that some water could be held over for flood irrigation. A gated pipe was set below the open pipe to facilitate irrigation.

The dams at each of the reservoirs are of earthfill construction. The dams have an emergency spillway cut in sandstone bedrock

TABLE 1.—*Reservoirs in Cornfield Wash*

Reservoir	Date constructed	Uncontrolled drainage area (sq mi)	Initial capacity		Capacity in October 1960		Diameter of outlet pipe (inches)
			Acre-ft	Acre-ft per sq mi	Acre-ft	Acre-ft per sq mi	
1	1950	0.29	24.0	82.8	10.3	35.5	8
2	1950	.87	54.1	62.2	45.0	51.7	8
3	1950	.25	5.9	23.6	2.6	10.4	------
4	1950	1.18	22.1	18.7	17.4	14.7	------
5	1950	1.04	9.2	8.8	3.0	2.9	10
6	1950	[1] 2.77	44.9	16.2	6.2	2.8	[2] 6
7	1950	[3] 1.07	15.0	14.0	6.1	11.7	10
8 [4]	------	------	------	------	------	------	------
9	1950	.09	4.6	51.1	3.1	34.4	------
10	1950	[5] 3.05	48.6	15.9	37.2	18.5	8
11	1950	[6] 3.03	166.8	55.0	88.7	31.7	[7] 24
12	1950	[8] 7.33	323.6	44.1	127.5	18.0	[7] 24
13	1950	.33	7.4	22.4	.3	.9	------
Total	------	21.30	------	------	------	------	------
15 [9]	May 1953	1.04	17.9	17.2	17.8	17.1	10
16 [9]	Apr. 1953	.55	28.9	52.5	26.8	48.7	10
17	May 1954	.59	18.3	31.0	16.6	28.1	10
18	Oct. 1956	.02	4.4	220.0	4.4	220.0	------
19	Oct. 1956	.18	13.4	74.4	13.4	74.4	------
20	Oct. 1956	.26	28.1	108.1	26.2	100.8	10
21	Oct. 1956	.03	8.2	27.3	8.2	27.3	------
Total	------	------	845.4	------	460.8	------	------

[1] Reduced to 2.18 sq mi by construction of reservoir 17.
[2] Reservoir has 3 outlet pipes.
[3] Reduced to 0.52 sq mi by construction of reservoir 16.
[4] Diversion dam for spreader system.
[5] Reduced to 2.01 sq mi by construction of reservoir 15.
[6] Reduced to 2.80 sq mi by construction of reservoirs 18, 19, and 21.
[7] The gated pipes have an 8-in. diameter.
[8] Runoff from drainage area is influenced to some degree by spreader dikes below diversion dam 8; drainage area reduced to 7.07 sq mi by construction of reservoir 20.
[9] Dam breached July 22, 1954; reconstructed May 1955.

where possible; where sandstone bedrock is absent, the spillway is cut in shale or alluvium along one of the abutments.

Inflow into each of the reservoirs was measured by taking weekly or more frequent readings of the gages, which showed the water level and maximum stage that had occurred since the last visit. Continuous water-stage recorders were installed at reservoir 2 in 1953, reservoir 5 in 1955, reservoirs 6 and 7 in 1956, reservoir 10 in 1958, and reservoir 12 in 1959. A crest-stage gage was substituted for the continuous water-stage recorder at reservoir 5 in 1956. Crest-stage gages were installed at all other reservoirs.

A typical stage graph constructed from the crest-stage data is shown in figure 7. The change in stage during inflow was inferred from the graphs and converted to volumes of runoff through the

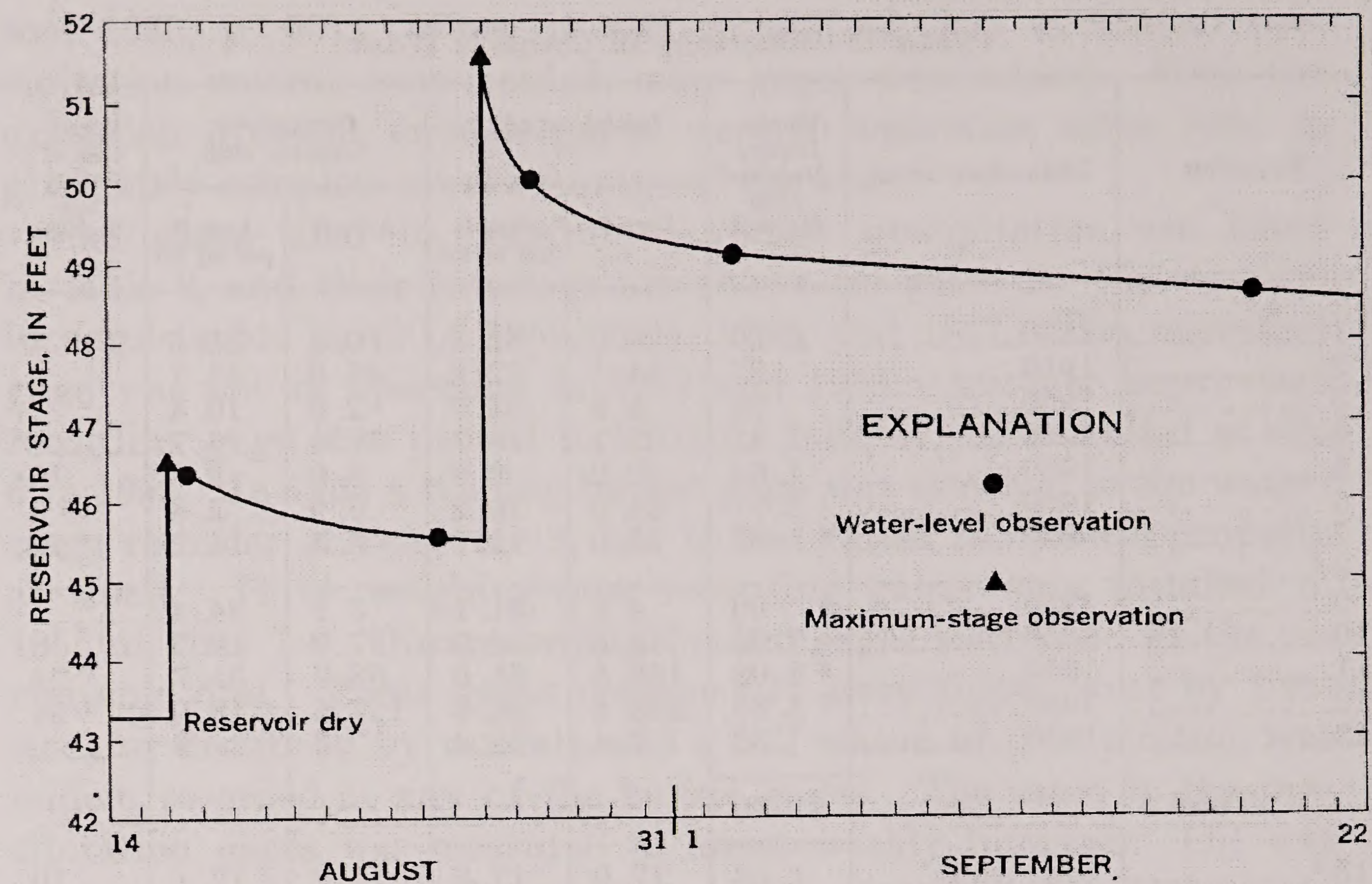

FIGURE 7.—Water stage for August 13 to September 22, 1959, at reservoir 4.

use of stage-capacity curves for each reservoir. Adjustments for changes in capacities resulting from deposition of sediment were made on the basis of the annual reservoir surveys. Measurements of runoff were made only during the warm period—May through October—because runoff is practically negligible during the remainder of the year.

The storage capacity of several of the reservoirs was insufficient for all the runoff they received, and, therefore, spill occurred. However, except for three occasions when storms caused spill from the lowest reservoir, the aggregate capacity of the reservoirs was sufficient to store all the runoff from the basin. Thus, a measurement of the total composite runoff from the basin is available. Spill from individual reservoirs not equipped with recording gages was estimated by the method described by Kennon and Peterson (1960, p. 87). Spill from reservoirs with recording gages was computed by inferring average stage to a stage-discharge rating of the spillway.

The reservoirs were surveyed shortly after their construction and again after each runoff season, and area and capacity curves were developed after each survey. The reduction in capacity between surveys was considered to be a measure of the accretion of sediment for the season. No adjustments were made for sediment that may have passed through the outlet or spillways or for compaction of sediment.

LAND TREATMENT

Figure 8 shows an example of the wire barriers built in 1956 across the channels above reservoirs 6, 7, 11, and 12 to induce sediment aggradation. Range lines were established in 1956 across the channel above reservoir 7, and annual surveys were made thereafter to determine the sediment aggradation that could be accredited to the wire barrier. Detailed surveys were made of the channels at the other barriers in 1956 and again in 1960 to determine the amount of sediment deposited in the channel during that period. The effects of the barriers are discussed in the section "Effects of land treatment."

Plate 1 shows the watersheds in which range-pitting treatment has been applied. Watersheds that were not treated were used as

FIGURE 8.—Hog-wire sediment barrier upstream from reservoir 7. Photograph by F. A. Branson, 1960.

controls for detecting the effects of treatment. The effects of range-pitting treatment on watersheds are discussed in the section "Effects of land treatment."

PRECIPITATION

TABULATION OF DATA

The precipitation measurements in table 2 represent the average catch of all the gages in the basin and the extremes of the highest and lowest precipitation for individual storm periods at different gages. With the exception of 1956, enough gages were in operation after 1954 to compute a standard deviation and a coefficient of variability of the catch for each storm period.

Data on storm precipitation obtained from recording gage 6 are given in table 3. Maximum 30-minute and 60-minute amounts and storm total are given.

TABLE 2.—*Precipitation in Cornfield Wash basin for warm seasons, May through October 1951–60*

Period of record	Gages in operation	Precipitation						Ratio standard deviation to average
		Average of all gages (inches)	Minimum		Maximum		Standard deviation (inches)	
			Inches	Gage	Inches	Gage		
1951								
July 18–Sept. 12	6, 10	3.91						
1952								
Mar. 6–Sept. 30	6	7.05						
1953								
May 1–June 18	6, 10	0						
June 19–July 14	2	.2						
July 15	2	.2						
July 16–17	2	2.50						
July 26–31	1–6, 11	1.57	0.5	1	1.8	3		
Aug. 11	1, 2, 4, 6	.32	0	1	.6	4		
Aug. 12–Sept. 3		0						
Total		4.79						
1954								
Mar. 21–24	1, 4, 5, 6, 10	1.0	.50	1	1.9	4		
May 10	1, 6	.22	.20	1	.25	6		
June 4–July 8	1, 6, 13	1.1	.8	1	1.4	13		
July 9–17	1–6, 10, 13, 15	.93	.20	1	1.68	15	0.54	0.58
July 21–23	1–6, 10, 11, 12, 13, 15	2.4	.92	5	2.98	10	.60	.28
July 31–Aug. 17	1–4, 6, 11–13	1.13	.51	6	1.46	13	.34	.30
Aug. 25–Sept. 2	1, 3, 4–6, 10–12, 15	.24	0	3, 5, 6	.48	10	.21	.88
Sept. 3–30	1, 3–6, 10–12, 15	2.26	1.98	15	3.00	3	.32	.14
Total		9.02						
Average							.40	
1955								
May 1–July 1	5, 6	1.0	1.0	5	1.0	6		
July 2–20	2, 5, 6	.39	.36	2	.44	6		
July 21–30	1–6, 10, 11, 13, 15	2.03	1.15	6	3.48	1	.69	.34
Aug. 4–10	2–6, 10–13, 15	2.04	1.35	11	2.74	2	.52	.25
Aug. 13–16	1–6, 10–13, 15	.55	0	1	1.26	12	.32	.58
Aug. 17–24	1–6, 10–13, 15	.88	.20	1	1.50	11, 12	.48	.55
Aug. 25–30	1, 3–6, 10–13, 15	.36	.1	1	.60	15	.18	.50
Aug. 31–Sept. 7	1–6, 10–13, 15	.05	0	6	.15	4	.06	1.20
Sept. 8–30	3, 5, 6	.17	.05	6	.25	3		
Total		7.47						
Average							.38	

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Table 2.—*Precipitation in Cornfield Wash basin for warm seasons, May through October 1951–60*—Continued

Period of record	Gages in operation	Precipitation						Ratio standard deviation to average
		Average of all gages (inches)	Minimum		Maximum		Standard deviation (inches)	
			Inches	Gage	Inches	Gage		
1956								
May 31–Oct. 11	6, 7, 8, 9	2.16						
1957								
Apr. 12–June 2	6, 7, 8, 9	3.61	3.05	6	3.74	9		
June 6–July 2	6, 7, 8, 9	.40	.30	8	.57	6		
July 2–10	7, 8, 9	.03	.02	7, 8	.04	9		
July 17–24	3–5, 6–13, 15, 18	.38	.07	9	.66	3	0.17	0.45
July 24–31	3–5, 6–13, 15, 18	1.54	.46	6	2.38	11	.53	.34
July 31–Aug. 6	3–13, 15, 18	1.37	.42	9	2.65	11	.65	.47
Aug. 6–14	3–13, 15, 18	1.28	.36	18	1.84	13	.42	.33
Aug. 14–21	3–13, 15, 18	.39	.03	9	.92	15	.23	.59
Aug. 21–27	3–13, 15, 18	.81	.44	7	1.14	12	.21	.26
Aug. 27–Sept. 3	3–13, 15, 18	.68	.46	7	.88	10	.14	.21
Sept. 10–17	3–5, 7–13, 15, 18	.08	0	15, 18	.18	3, 4, 13	.07	.88
Oct. 11–24	1–5, 10–13, 15, 18	1.83	1.06	15	2.07	4	.34	.19
Total		12.40						
Average							.31	
1958								
June 19–25	1, 3, 4, 6–10, 12, 13, 15, 18	.02	0	[1]	.19	15		
June 25–July 2	1, 3, 4, 6–9, 12, 13, 15, 18	.03	0	[1]	.24	13		
July 2–8	1, 4, 6–9, 11–13, 15, 18	.08	0	[1]	.50	18		
July 15–22	1, 3, 4, 6–9, 11–13, 18	.24	.10	7	.44	4	.12	.50
July 22–29	1, 3–9, 11–13, 15, 18	.01	0	[1]	.10	7		
July 29–Aug. 4	1, 3–9, 12, 13, 15, 18	.03	0	[1]	.14	12		
Aug. 4–11	1, 3–9, 11–13, 15, 18	.65	.37	9	1.00	5	.19	.29
Aug. 11–18	1, 3–9, 12, 13, 15, 18	.24	0	15, 18	.87	4	.23	.96
Aug. 18–25	1, 3–9, 11–13, 15, 18	1.09	.62	6	1.67	15	.26	.24
Sept. 2–10	1, 3–9, 11–13, 15, 18	.20	0	4	.58	9	.19	.95
Sept. 10–16	1, 3–9, 11–13, 15, 18	.40	.28	1	.52	15	.06	.15
Sept. 16–Oct. 2	1, 3–9, 11–13, 15, 18	.28	.18	6	.48	5	.06	.21
Oct. 2–15	1, 3–5, 7–9, 11–13, 15, 18	.49	.41	3	.54	8	.04	.08
Total		3.76						
Average							.14	
1959								
May 14–16	1, 3, 5, 9, 12, 13, 15, 18	.29	.12	15	.44	1	.12	.41
June 16–23	1, 3–9, 11, 12, 15, 18	.88	.66	6	1.16	18	.16	.18
June 30–July 16	1, 3, 5–9, 11–13, 15, 18	.33	.16	1, 15	.48	5	.10	.30
July 16–28	1, 4–9, 12, 13, 15, 18	.74	.40	1	1.16	13	.27	.36
July 28–Aug. 3	1, 3–9, 11–13, 15, 18	.07	0	[1]	.24	15	.08	1.14
Aug. 3–13	1, 3–9, 11–13, 15, 18	.38	.24	15	.56	1	.09	.24
Aug. 13–15	1, 3–9, 11–13, 15, 18	.77	.24	1	1.20	3	.26	.34
Aug. 15–24	1, 5–9, 11–13, 15, 18	.35	.05	9	.72	15	.22	.63
Aug. 24–26	1, 3–9, 11–13, 15, 18	.51	.32	3, 13	.90	4	.18	.35
Sept. 10–25	6–9	.11	.08	6	.19	9		
Sept. 12–13	6–9	.88	.70	6	.98	8		
Total		5.31						
Average							.16	
1960								
June 1–7	1, 3–13, 15, 18	.03	0	4, 13	.07	7	.02	.67
June 7–13	1, 4–13, 15, 18	.01	0	[1]	.10	10		
July 6–14	1, 4–13, 15, 18	.14	0	18	.20	13, 18	.07	.50
July 14–21	1, 3, 4, 6, 7, 9–13, 15, 18	.09	0	10, 11, 18	.29	9	.09	1.00
July 21–28	1, 3, 4, 6–13, 15–18	.01	0	[1]	.12	4		
July 28–Aug. 4	1, 3, 5–9, 11, 15, 18	.36	.10	9	.88	3	.27	.75
Aug. 4–10	1, 3–13, 15, 18	.15	0	[1]	.52	5	.16	1.07
Aug. 10–18	1, 3, 4, 6–13, 15, 18	.24	.08	1	.44	11	.09	.38
Aug. 18–25	1, 3, 4, 6–13, 15, 18	.32	.12	6	.58	8	.13	.41
Sept. 9–15	1, 3–13, 15, 18	.03	0	[1]	.10	3		
Oct. 1–25	1, 3–10, 12, 15, 18	3.46	3.11	6	3.68	4	.23	.07
Total		4.84						
Average							.13	

[1] Several.

TABLE 3.—*Major storm precipitation measured at recording gage 6*

Date	Precipitation (inches)		
	Maximum		Total
	30 minutes	60 minutes	
1951			
July 31	1. 06	1. 24	1. 55
Aug. 21	----------	----------	. 48
1952			
Apr. 19	----------	----------	. 65
Apr. 27	----------	----------	. 59
June 27	----------	----------	. 74
July 1–19	----------	----------	[1] 1. 80
July 22–Aug. 4	----------	----------	[1] . 80
Aug. 6–28	----------	----------	[1] 1. 00
Aug. 25	. 22	----------	. 65
1953 [2]			
1954			
July 9	. 60	. 83	. 86
July 21	. 89	. 95	1. 00
July 22	----------	----------	. 80
Sept. 12	. 40	----------	. 78
Sept. 24	----------	----------	. 65
Sept. 25	. 40	. 40	. 40
1955			
July 11	----------	----------	. 44
July 27	----------	----------	. 55
Aug. 4	. 40	. 40	. 40
Aug. 6	1. 05	1. 09	1. 19
Aug. 7	----------	----------	. 33
1956			
July 19	. 47	. 50	. 50
Aug. 8	. 22	. 22	. 48
1957			
July 22	. 46	. 46	. 48
July 24	. 49	. 49	. 49
Aug. 5	. 31	. 42	. 42
Aug. 6	. 59	. 66	. 77
1958 [2]			
1959			
Aug. 14	. 42	. 83	. 83
Aug. 24	. 28	. 32	. 52
1960			
Aug. 6	. 35	. 35	. 35
Oct. 15–19	----------	----------	2. 60

[1] Gage inoperative.
[2] Gage not operated as a recorder during season.

MAGNITUDE AND FREQUENCY

During the first 5 years of the study there was at least one major thunderstorm during each season (Kennon and Peterson, 1960, p. 61). Much of the total seasonal precipitation fell during these short torrential downpours. For instance, the total rainfall meas-

ured at gage 6 for the storm of July 31, 1951, was 1.55 inches, which is about 40 percent of the seasonal total. About 1.06 inches, or 25 percent of the seasonal total, fell in the first 30 minutes.

Beginning in 1956 much of the precipitation fell in small showers or was from large frontal storms of low-rainfall intensities. The following examples are given to illustrate the marked differences in the precipitation intensities in the 1951–55 and 1956–60 periods. The year 1957 was "wet." The seasonal precipitation of 12.40 inches computed as the average of all gages is the maximum of the 10 years of record; however, the maximum 30-minute and 60-minute amounts were not high compared to the maximum of the 1951–55 period. The maximum 30-minute rainfall in 1957 was only 0.59 inch. With the maximum annual 30-minute rainfalls for the 10 years of record arranged in descending order, the 0.59-inch amount for 1957 would be ranked as 6. The largest 5 maximum seasonal 30-minute storms occurred in the first 5 years of record (table 3).

The maximum storm rainfall for 1960, compared with that of 1951, is another example of contrasting differences in rainfall intensities. The maximum storm of 1960 produced 2.60 inches of precipitation, or about 50 percent of the total for the season. As stated, 40 percent of the total seasonal precipitation in 1951 fell during the storm of July 31, 1951, and of this amount, 25 percent fell during the first 30 minutes. In contrast, the 2.60 inches in 1960 was from a frontal storm that produced precipitation of low intensity for 4 days.

Although the maximum 30-minute amounts for the 1951–55 period were considerably higher than those for the 1956–60 period, they were not abnormally high for the area. According to studies by Yarnell (1935), a thunderstorm in the Cornfield Wash area that produces 1 inch of precipitation in 30 minutes may be expected on the average of once every 5 years. Thus, the maximum annual 30-minute amounts for the 10 years of record are about what would be expected on the average, according to Yarnell.

Inasmuch as a significant change in intensity of precipitation apparently has occurred in the Cornfield Wash basin since 1955, perhaps the areal extent of storms and the areal variability of storm amounts also have changed. A check of the changes in areal coverage and amounts was made by comparing the variability of storm amounts before 1955 against those after 1955. Since August 1957 there have been only three storm periods—October 11–24, 1957, August 18–25, 1958, and October 1–25, 1960—in which average precipitation amounts exceeded 1.00 inch (table 3). The standard deviations for the three storms are relatively low, indicating that

perhaps each was from a general storm producing uniform rain over the basin.

RUNOFF

Runoff, or the part of precipitation that appears in surface streams, is such a complicated hydrologic phenomenon that it cannot be discussed fully in a short report. In this report a simple discussion of runoff is given by using a hypothetical basin of infinitesimal size ΔA.

The storm runoff from a watershed of size ΔA can be expressed by the equation:

$$\Delta R = P\Delta A - (\Delta Vr + \Delta Vf),$$

in which

ΔR = the total water yield from an infinitesimal area (ΔA) as a result of the total precipitation (P) occurring during the storm duration (TR);

ΔVr = the total surface retention on ΔA (Linsley and others, 1949) during TR; and

ΔVf = the total water lost by infiltration on ΔA during TR.

If the only losses from ΔR were ΔVr and ΔVf, the runoff from any basin of larger size would be equal to the summations of the ΔR's of the basin. This would be true even though there was considerable variation in the variables P, ΔVr, and ΔVf.

Obviously, there is another loss—hereafter called transit loss—when ΔR is conveyed from a basin of size ΔA to the measuring site of a larger basin. The transit loss (ΔVt) is produced by infiltration and evaporation during overland and channel flow. The transit loss varies with, among other things, the time it takes for the water to move from the basin of size ΔA to the measuring site of the larger basin. The total runoff from a large basin would be equal to the summation of the ΔR's less the summation of the transit losses, or in equation form:

$$R = \sum [P\Delta A - (\Delta Vr + \Delta Vf + \Delta Vt)].$$

It is plain that runoff is controlled by precipitation, basin characteristics, and evaporation, as shown above. Because evaporation is nearly equal over large areas (Kohler and others, 1959), the relations between the runoff-precipitation and runoff-basin characteristics are given the most consideration in this section.

TABULATION OF DATA

Storm-runoff data from 1956 to 1960 are given in table 4, and the data for the initial 5 years of study (1951–55) are given in the report by Kennon and Peterson (1960, p. 74–87). The seasonal-

runoff and sediment-deposition data from 1951 to 1960 are given in table 5. However, the seasonal runoff does not include the spill from upstream reservoirs.

In table 4, inflow stored is the amount permanently and temporarily impounded, and total inflow includes spill from upstream reservoirs. In tables 4 and 5, inflow, in acre-feet per square mile, includes only inflow from the uncontrolled watershed. Permanently stored inflow is that part that is impounded below the elevation of the invert of the outflow pipe. The permanently stored inflow reduces the surface flow leaving the basin. Temporarily stored inflow is the amount that is impounded above the elevation of the invert of the outflow pipe and below the elevation of the emergency spillway.

The large sediment accumulation in several of the reservoirs caused a decrease in the accuracy of the data for storm runoff. The sediment deposits affected the accuracy of runoff data from major storms by causing large volumes of spill due to decreased storage capacity and uncertainty in the accuracy of runoff data from small storms by consuming an unmeasured amount of runoff as seepage into voids. The amount of water necessary to fill the voids after an extended dry period may be a large percentage of the runoff from small storms.

The ungaged spill in this study was computed by the following equation (Kennon and Peterson, 1960, p. 87):

$$V=S\left[1+\frac{CQ\sqrt{A}}{S+S_1}\right],$$

in which

V=volume of spill, in acre-feet;
A=drainage area, in square miles;
S=surcharge: the volume of water temporarily stored in the reservoir above the spillway crest, in acre-feet;
S_1=volume of runoff impounded below spillway level, in acre-feet;
Q=maximum rate of spill, in cubic feet per second; and
C=a coefficient relating the volume and rate of spill to the surcharge for each reservoir.

C was computed from the gaged inflow to reservoir 2 by the following equation:

$$C=\frac{V-S}{Q\sqrt{A}}.$$

A rough check was made of the accuracy of the computed spill by comparing it with the gaged spill. Recording gages were in operation at reservoir 5 in the summer of 1955 and at reservoirs 6 and 7 after 1956. From these gaged records, 13 individual storms

Table 4.—*Storm runoff measured in reservoirs in Cornfield Wash*

Reservoir 1

Drainage area.—0.29 sq mi.
Records available.—July 1951 to October 1960.
Gage.—Crest-stage gage. Datum of gage is about 6,420 ft above mean sea level.
Runoff and discharge determinations.—Contents of reservoir and volume of inflow and outflow computed from a stage-capacity curve of the reservoir.
Capacity.—Original, 24.0 acre-ft, Apr. 23, 1951; 10.3 acre-ft, October 1960.
Remarks.—Records fair, except that those for spill are poor.

Date of flow	Gage height (feet)		Inflow stored (acre-ft)	Spill (acre-ft)	Inflow	
	Before inflow	After inflow			Total (acre-ft)	Acre-ft per sq mi
1956						
July 31	[1] 52. 2	55. 2	3. 7	0	3. 7	12. 8
Aug. 16	54. 4	56. 2	3. 5	0	3. 5	12. 1
Total			7. 2	0	7. 2	24. 9
1957						
June 2	[1] 52. 2	55. 0	2. 7	0	2. 7	9. 3
July 22	53. 1	53. 3	. 1	0	. 1	. 3
July 24	53. 2	56. 6	5. 5	0	5. 5	19. 0
Aug. 6–8	56. 1	60. 1	7. 3	8. 0	15. 3	52. 8
Aug. 12	58. 6	58. 9	. 2	1. 5	1. 7	5. 9
Aug. 16	58. 4	58. 6	. 8	0	. 8	2. 8
Aug. 24	57. 8	58. 1	1. 0	0	1. 0	3. 4
Aug. 31	57. 6	58. 4	3. 2	0	3. 2	11. 0
Total			20. 8	9. 5	30. 3	104. 5
1958 [2]						
1959						
June 21	[1] 53. 2	54. 3	1. 0	0	1. 0	3. 4
July 24	53. 3	53. 9	. 4	0	. 4	1. 4
Aug. 14	53. 3	53. 7	. 2	0	. 2	. 7
Aug. 21	53. 5	53. 7	. 2	0	. 2	. 7
Aug. 24	53. 6	54. 5	21. 0	0	1. 0	3. 4
Aug. 28	54. 4	54. 5	. 3	0	. 3	1. 0
Oct. 12	53. 5	55. 6	3. 0	0	3. 0	10. 3
Total			6. 1	0	6. 1	21. 0
1960						
Mar. 5–6	[1] 53. 1	56. 5	5. 4	0	5. 4	18. 6
Oct. 16–18	[1] 53. 1	57. 5	7. 0	0	7. 0	24. 1
Total			12. 4	0	12. 4	42. 7

[1] Reservoir dry at beginning of flow. Elevation before inflow is the elevation of the low point of the reservoir.
[2] No flow.

TABLE 4.—*Storm runoff measured in reservoirs in Cornfield Wash*—Continued

Reservoir 2

Drainage area.—0.87 sq mi.
Records available.—July 1951 to October 1960.
Gage.—Warer-stage recorder. Datum of gage is about 6,520 ft above mean sea level.
Runoff and discharge determinations.—Contents of reservoir and volume of inflow and outflow computed from a stage-capacity curve of the reservoir.
Capacity.—Original, 54.1 acre-ft, April 1951; 45.0 acre-ft, October 1960.
Remarks.—Records good.

Date of flow	Gage height (feet)		Inflow stored (acre-ft)	Spill (acre-ft)	Inflow	
	Before inflow	After inflow			Total (acre-ft)	Acre-ft per sq mi
1956						
July 19	[1] 79. 1	79. 7	0. 2	0	0. 2	0. 2
July 28	79. 5	81. 2	. 5	0	. 5	. 6
Aug. 16	80. 7	81. 3	. 2	0	. 2	. 2
Total			. 9	0	. 9	1. 0
1957						
Apr. 10–12	[1] 79. 1	81. 1	. 5	0	. 5	. 6
June 2	80. 4	91. 8	14. 0	0	14. 0	16. 1
June 11	87. 3	87. 4	. 1	0	. 1	. 1
July 24	85. 4	89. 9	5. 7	0	5. 7	6. 6
July 25–26	87. 7	87. 9	. 2	0	. 2	. 2
Aug. 5	87. 2	92. 5	15. 1	0	15. 1	17. 4
Aug. 24	87. 3	87. 9	. 7	0	. 7	. 8
Aug. 29–30	87. 5	88. 2	1. 0	0	1. 0	1. 1
Aug. 31	87. 6	88. 1	. 6	0	. 6	. 7
Oct. 12	86. 3	90. 0	5. 1	0	5. 1	5. 9
Oct. 20	87. 4	89. 0	2. 6	0	2. 6	3. 0
Oct. 21	87. 7	87. 8	. 1	0	. 1	. 1
Nov. 6	87. 3	87. 5	. 2	0	. 2	. 2
Total			45. 9	0	45. 9	52. 8
1958 [2]						
1959						
July 25	80. 2	81. 3	. 2	0	. 2	. 2
July 28	81. 2	82. 4	. 6	0	. 6	. 7
Aug. 14–15	81. 9	86. 9	3. 1	0	3. 1	3. 6
Aug. 24	86. 1	86. 4	. 1	0	. 1	. 1
Oct. 3	84. 6	86. 5	1. 4	0	1. 4	1. 6
Oct. 30	85. 4	87. 4	1. 6	0	1. 6	1. 8
Total			7. 0	0	7. 0	8. 0
1960						
Mar. 5–6	85. 0	86. 8	1. 3	0	1. 3	1. 5
Oct. 16–18	[1] 80. 0	88. 1	5. 0	0	5. 0	5. 7
Total			6. 3	0	6. 3	7. 2

[1] Reservoir dry at beginning of inflow. Elevation before inflow is the elevation of the low point of the reservoir.
[2] No flow.

TABLE 4.—*Storm runoff measured in reservoirs in Cornfield Wash*—Continued

Reservoir 3

Drainage area.—0.25 sq mi.

Records available.—July 1951 to October 1960.

Gage.—Crest-stage gage. Datum of gage is about 6,660 ft above mean sea level.

Runoff and discharge determinations.—Contents of reservoir and volume of inflow and outflow computed from a stage-capacity curve of the reservoir.

Capacity.—Original, 5.9 acre-ft, April 1951; 2.6 acre-ft, October 1960.

Remarks.—Records fair, except that those for spill are poor.

Date of flow	Gage height (feet)		Inflow stored (acre-ft)	Spill (acre-ft)	Inflow	
	Before inflow	After inflow			Total (acre-ft)	Acre-ft per sq mi
1956						
July 28	[1] 41. 1	45. 5	1. 6	0	1. 6	6. 4
1957						
June 2	[1] 41. 2	48. 5	2. 7	2. 3	5. 0	20. 0
July 22	45. 2	48. 3	1. 9	. 8	2. 7	10. 8
July 24	47. 3	49. 1	. 1	4. 3	4. 4	17. 6
Aug. 5	47. 3	48. 1	. 4	. 6	1. 0	4. 0
Aug. 6	47. 7	48. 9	0	3. 9	3. 9	15. 6
Aug. 12	47. 6	48. 5	. 2	1. 4	1. 6	6. 4
Aug. 16	47. 6	47. 9	0	. 3	. 3	1. 2
Aug. 24	47. 5	48. 1	. 1	. 7	. 8	3. 2
Aug. 31	47. 6	47. 9	. 2	. 2	. 4	1. 6
Oct. 12	46. 3	48. 0	1. 1	. 4	1. 5	6. 0
Total			6. 7	14. 9	21. 6	86. 4
1958 [2]						
1959						
July 24	[1] 42. 7	43. 8	. 2	0	. 2	. 8
Aug. 14	43. 2	48. 0	3. 1	0	3. 1	12. 4
Aug. 25	47. 1	47. 2	. 1	0	. 1	. 4
Oct. 12	45. 4	46. 5	. 8	0	. 8	3. 2
Oct. 30	46. 0	47. 8	. 7	0	. 7	2. 8
Total			4. 9	0	4. 9	19. 6
1960						
Mar. 5–6	44. 0	47. 0	1. 8	0	1. 8	7. 2
Oct. 16–18	[1] 42. 5	44. 1	. 3	0	. 3	1. 2
Total			2. 1	0	2. 1	8. 4

[1] Reservoir dry at beginning of inflow. Elevation before inflow is the elevation of the low point of the reservoir.
[2] No flow.

219-285 O—66——5

TABLE 4.—*Storm runoff measured in reservoirs in Cornfield Wash*—Continued

Reservoir 4

Drainage area.—1.18 sq mi.
Records available.—July 1959 to October 1960.
Gage.—Crest-stage gage. Datum of gage is about 6,700 ft above mean sea level.
Runoff and discharge determinations.—Contents of reservoir and volume of inflow and outflow computed from a stage-capacity curve of the reservoir.
Capacity.—Original, 22.1 acre-ft, April 1951; 17.4 acre-ft, October 1960.
Remarks.—Records good.

Date of flow	Gage height (feet)		Inflow stored (acre-ft)	Spill (acre-ft)	Inflow	
	Before inflow	After inflow			Total (acre-ft)	Acre-ft per sq mi
1956 [1]						
1957						
June 2	[2] 41.8	52.6	12.3	0	12.3	10.4
July 24	48.2	50.6	4.4	0	4.4	3.7
Aug. 5	49.3	52.6	8.0	0	8.0	6.8
Aug. 6	51.5	52.8	4.3	0	4.3	3.6
Aug. 24	51.5	52.3	2.5	0	2.5	2.1
Aug. 29	52.0	52.2	.8	0	.8	.7
Oct. 12	50.5	50.8	.7	0	.7	.6
Oct. 20	50.5	50.9	.8	0	.8	.7
Total			33.8	0	33.8	28.6
1958 [1]						
1959						
Aug. 14	[2] 43.2	46.5	1.0	0	1.0	.8
Aug. 24	45.6	51.6	9.1	0	9.1	7.7
Total			10.1	0	10.1	8.5
1960						
Mar. 5–6	45.6	47.4	1.2	0	1.2	1.0

[1] No flow.
[2] Reservoir dry at beginning of flow. Elevation before inflow is the elevation of the low point of the reservoir.

TABLE 4.—*Storm runoff measured in reservoirs in Cornfield Wash*—Continued

Reservoir 5

Drainage area.—1.04 sq mi.

Records available.—July 1951 to October 1960.

Gage.—Crest-stage gage. Datum of gage is about 6,760 ft above mean sea level.

Runoff and discharge determinations.—Contents of reservoir and volume of inflow and outflow computed from a stage-capacity curve of the reservoir.

Capacity.—Original, 9.2 acre-ft, April 1951; 3.0 acre-ft, October 1960.

Remarks.—Records poor. Water-stage recorder moved to reservoir 6 in June 1956.

Date of flow	Gage height (feet)		Inflow stored (acre-ft)	Spill (acre-ft)	Inflow	
	Before inflow	After inflow			Total (acre-ft)	Acre-ft per sq mi
1956						
July 31	[1] 48. 8	49. 2	0. 4	0	0. 4	0. 4
Aug. 16	48. 9	49. 5	. 4	0	. 4	. 4
Aug. 30	48. 9	49. 5	. 4	0	. 4	. 4
Total			1. 2	0	1. 2	1. 2
1957						
June 2	[1] 48. 8	51. 6	2. 0	0	2. 0	1. 9
July 22	49. 9	50. 4	. 3	0	. 3	. 3
July 24	50. 3	52. 4	2. 4	. 8	3. 2	3. 1
Aug. 5	51. 9	52. 6	. 3	2. 9	3. 2	3. 1
Aug. 6	52. 1	54. 0	0	18. 4	18. 4	17. 7
Aug. 12	51. 9	53. 3	. 4	8. 3	8. 7	8. 4
Aug. 16	51. 9	52. 1	. 5	0	. 5	. 5
Aug. 24	51. 8	53. 0	. 6	8. 0	8. 6	8. 3
Aug. 31	51. 8	52. 1	. 5	0	. 5	. 5
Oct. 12	50. 0	53. 1	. 3	7. 9	8. 2	7. 9
Total			7. 3	46. 3	53. 6	51. 5
1958 [2]						
1959						
Aug. 14	[1] 49. 4	51. 3	1. 8	0	1. 8	1. 7
Aug. 21	50. 7	51. 7	1. 4	0	1. 4	1. 3
Aug. 24	51. 6	53. 1	1. 5	3. 7	5. 2	5. 0
Oct. 12	50. 3	51. 5	1. 6	0	1. 6	1. 5
Oct. 30	51. 0	51. 9	1. 4	0	1. 4	1. 3
Total			7. 7	3. 7	11. 4	11. 0
1960						
Mar. 5–6	[1] 49. 4	52. 7	4. 7	1. 8	6. 5	6. 2
Aug. 23	[1] 49. 4	51. 9	2. 8	0	2. 8	2. 7
Oct. 16–18	50. 2	52. 3	3. 2	. 8	4. 0	3. 8
Total			10. 7	2. 6	13. 3	12. 8

[1] Reservoir dry at beginning of inflow. Elevation before inflow is the elevation of the low point of the reservoir.
[2] No flow.

TABLE 4.—*Storm runoff measured in reservoirs in Cornfield Wash*—Continued

Reservoir 6

Drainage area.—2.77 sq mi from April 1951 to May 1954 and from July 23, 1954, to May 1955 while dam for reservoir 17 was breached; 2.18 sq mi from May 1954 to July 22, 1954, and from May 1955 to October 1960.
Records available.—July 1951 to October 1960.
Gage.—Water-stage recorder. Datum of gage is about 6,600 ft above mean sea level.
Runoff and discharge determinations.—Contents of reservoir and volume of inflow and outflow computed from a stage-capacity curve of the reservoir.
Capacity.—Original, 44.9 acre-ft, April 1951; 6.2 acre-ft, October 1960.
Remarks.—Records fair, except that those for spill are poor. Outflow temporarily impounded by spreader system below reservoir. Water-stage recorder was installed in June 1956.

Date of flow	Gage height (feet)		Inflow stored (acre-ft)	Spill (acre-ft)	Inflow	
	Before inflow	After inflow			Total (acre-ft)	Acre-ft per sq mi
1956 [1]						
1957						
June 3	[2] 53. 8	56. 9	9. 9	0	9. 9	4. 5
July 22	[2] 53. 8	55. 5	2. 9	0	2. 9	1. 3
July 24–Aug. 31	55. 4	58. 8	5. 5	109. 5	115. 0	35. 1
Oct. 12	55. 2	57. 7	4. 6	11. 1	15. 7	3. 6
Total			22. 9	120. 6	143. 5	44. 6
1958 [1]						
1959						
Aug. 14–15	[2] 54. 6	56. 0	3. 1	. 7	3. 8	1. 7
Aug. 24–25	55. 2	57. 1	1. 6	6. 5	8. 1	2. 0
Oct. 30	[2] 54. 6	55. 9	3. 1	. 3	3. 4	1. 6
Total			7. 8	7. 5	15. 3	5. 3
1960						
Mar. 5–6	[2] 55. 2	57. 1	9. 5	2. 0	11. 5	4. 4
Oct. 16–18	[2] 55. 2	55. 4	1. 6	0	1. 6	. 4
Total			11. 1	2. 0	13. 1	4. 8

[1] No flow.
[2] Reservoir dry at beginning of inflow. Elevation before inflow is the elevation of the low point of the reservoir.

Table 4.—*Storm runoff measured in reservoirs in Cornfield Wash*—Continued

Reservoir 7

Drainage area.—1.07 sq mi from April 1951 to April 1953 and from July 10, 1954, to May 1955, while dam for reservoir 16 was breached; 0.52 sq mi from April 1953 to July 9, 1954, and from May 1955 to October 1960.

Records available.—July 1951 to October 1960.

Gage.—Water-stage recorder. Datum of gage is about 6,580 ft above mean sea level.

Runoff and discharge determinations.—Contents of reservoir and volume of inflow and outflow computed from a stage-capacity curve of the reservoir.

Capacity.—Original, 15.0 acre-ft, April 1951; 6.1 acre-ft, October 1960.

Remarks.—Records fair, except that those for spill are poor. Outflow temporarily impounded by spreader system below reservoir. Water-stage recorder was installed in June 1956.

Date of flow	Gage height (feet)		Inflow stored (acre-ft)	Spill (acre-ft)	Inflow	
	Before inflow	After inflow			Total (acre-ft)	Acre-ft per sq mi
1956						
July 19	[1] 87.8	90.0	0.6	0	0.6	1.2
July 22	89.8	90.1	.1	0	.1	.2
July 28	89.8	90.6	.4	0	.4	.8
Aug. 16	89.2	90.5	.6	0	.6	1.2
Total			1.7	0	1.7	3.3
1957						
June 3	[1] 87.8	91.6	9.0	1.1	10.1	19.4
July 22	88.3	90.4	.7	0	.7	1.3
July 24	89.8	93.1	3.4	0	3.4	6.5
Aug. 5	89.8	94.0	6.1	0	6.1	11.7
Aug. 6–7	93.6	95.3	1.5	11.0	12.5	24.0
Aug. 16	89.9	91.7	1.5	0	1.5	2.9
Aug. 24	90.0	90.1	.1	0	.1	.2
Aug. 29	89.9	90.7	.4	0	.4	.8
Aug. 30	90.4	91.0	.5	0	.5	1.0
Oct. 12	88.9	93.7	5.2	0	5.2	10.0
Total			28.4	12.1	40.5	77.9
1958 [2]						
1959						
July 28	[1] 88.0	88.8	.1	0	.1	.2
Aug. 1	[1] 88.0	89.5	.2	0	.2	.4
Aug. 14–15	88.3	94.7	7.4	2.1	9.5	18.3
Aug. 15	91.8	92.2	.4	0	.4	.8
Aug. 24	89.3	93.1	3.0	0	3.0	5.8
Oct. 2	[1] 88.0	90.5	.7	0	.7	1.3
Oct. 3	88.9	90.3	.4	0	.4	.8
Total			12.2	2.1	14.3	27.5
1960						
Mar. 5–6			[3] 4.0	0	[3] 4.0	[3] 7.7
Oct. 16–18	[1] 88.0	90.0	.3	0	.3	.6
Total			4.3	0	4.3	8.3

[1] Reservoir dry at beginning of flow. Elevation before inflow is the elevation of the low point of the reservoir.
[2] No flow.
[3] No record; flow estimated to be the same as that for reservoir 16.

TABLE 4.—*Storm runoff measured in reservoirs in Cornfield Wash*—Continued

Reservoir 9

Drainage area.—0.09 sq mi.
Records available.—June 1951 to October 1960.
Gage.—Crest-stage gage. Datum of gage is about 6,640 ft above mean sea level.
Runoff and discharge determinations.—Contents of reservoir and volume of inflow and outflow computed from a stage-capacity curve of the reservoir.
Capacity.—Original, 4.6 acre-ft, April 1951; 3.1 acre-ft, October 1960.
Remarks.—Records good. Outflow temporarily impounded by spreader system below reservoir.

Date of flow	Gage height (feet)		Inflow stored (acre-ft)	Spill (acre-ft)	Inflow	
	Before inflow	After inflow			Total (acre-ft)	Acre-ft per sq mi
1956						
July 19	[1] 69. 6	71. 6	0. 3	0	0. 3	3. 3
July 28	70. 6	72. 0	. 2	0	. 2	2. 2
Aug. 16	71. 3	72. 9	. 7	0	. 7	7. 8
Total			1. 2	0	1. 2	13. 3
1957						
June 2	[1] 69. 6	71. 8	. 4	0	. 4	4. 4
July 24	69. 7	72. 0	. 5	0	. 5	5. 6
Aug. 5	70. 2	73. 0	. 9	0	. 9	10. 0
Aug. 6	72. 9	74. 9	1. 3	0	1. 3	14. 4
Aug. 16	73. 2	73. 8	. 4	0	. 4	4. 4
Aug. 24	72. 6	73. 2	. 3	0	. 3	3. 3
Oct. 12	70. 8	71. 4	. 1	0	. 1	1. 1
Total			3. 9	0	3. 9	43. 3
1958 [2]						
1959						
Aug. 14	[1] 69. 7	73. 8	1. 4	0	1. 4	15. 6
Aug. 24	72. 0	73. 4	. 7	0	. 7	7. 8
Oct. 3	70. 3	71. 1	. 2	0	. 2	2. 2
Oct. 30	70. 2	71. 2	. 2	0	. 2	2. 2
Total			2. 5	0	2. 5	27. 8
1960						
Oct. 16–18	[1] 69. 8	71. 1	. 1	0	. 1	1. 1

[1] Reservoir dry at beginning of flow. Elevation before inflow is the elevation of the low point of the reservoir.
[2] No flow.

TABLE 4.—*Storm runoff measured in reservoirs in Cornfield Wash*—Continued

Reservoir 10

Drainage area.—3.05 sq mi from April 1951 to May 1953 and 2.01 sq mi thereafter.
Records available.—June 1951 to October 1960.
Gage.—Crest-stage gage from April 1951 to May 1958 and water-stage recorder thereafter. Datum of gage is about 6,580 ft above mean sea level.
Runoff and discharge determinations.—Contents of reservoir and volume of inflow and outflow computed from a stage-capacity curve of the reservoir.
Capacity.—Original, 48.6 acre-ft, April 1951; 37.2 acre-ft, October 1960.
Remarks.—Records good.

Date of flow	Gage height (feet)		Inflow stored (acre-ft)	Spill (acre-ft)	Inflow	
	Before inflow	After inflow			Total (acre-ft)	Acre-ft per sq mi
1956						
July 19	[1] 46.2	46.9	0.1	0	0.1	0.1
July 28	46.7	47.1	.1	0	.1	.1
Aug. 16	46.6	49.4	1.1	0	1.1	.5
Aug. 30	48.8	51.6	3.3	0	3.3	1.6
Total			4.6	0	4.6	2.3
1957						
June 2	[1] 46.3	55.6	12.3	0	12.3	6.1
July 22	49.2	49.3	.1	0	.1	.1
July 24	49.2	53.7	4.4	0	4.4	2.2
Aug. 5	50.4	56.8	18.7	0	18.7	9.3
Aug. 6	55.8	57.0	7.1	0	7.1	3.6
Aug. 16	50.6	50.9	.2	0	.2	.1
Aug. 24	50.6	50.8	.2	0	.2	.1
Aug. 31	50.6	50.8	.2	0	.2	.1
Oct. 12	50.0	53.8	5.1	0	5.1	2.5
Total			48.3	0	48.3	24.0
1958 [2]						
1959						
July 27	[1] 47.3	49.0	.6	0	.6	.3
Aug. 14	48.4	55.9	14.2	0	14.2	7.1
Aug. 23	50.3	51.5	.6	0	.6	.3
Aug. 24–25	50.3	54.5	8.2	0	8.2	4.1
Aug. 28	50.4	50.6	.1	0	.1	.1
Oct. 3	49.5	50.6	.5	0	.5	.2
Oct. 12	49.4	49.6	.1	0	.1	.1
Total			24.3	0	24.3	12.1
1960						
Mar. 5–6	[1] 48.5	50.2	.6	0	.6	.3
Oct. 16–18	[1] 48.5	52.5	3.4	0	3.4	1.7
Total			4.0	0	4.0	2.0

[1] Reservoir dry at beginning of inflow. Elevation before inflow is the elevation of the low point of the reservoir.
[2] No flow.

TABLE 4.—*Storm runoff measured in reservoirs in Cornfield Wash*—Continued

Reservoir 11

Drainage area.—3.03 sq mi April 1951 to September 1956 and 2.80 sq mi thereafter.
Records available.—July 1951 to October 1960.
Gage.—Crest-stage gage. Datum of gage is about 6,480 ft above mean sea level.
Runoff and discharge determinations.—Contents of reservoir and volume of inflow and outflow computed from a stage-capacity curve of the reservoir.
Capacity.—Original, 166.8 acre-ft, April 1951; 88.7 acre-ft, October 1960.
Remarks.—Records fair.

Date of flow	Gage height (feet)		Inflow stored (acre-ft)	Spill (acre-ft)	Inflow	
	Before inflow	After inflow			Total (acre-ft)	Acre-ft per sq mi
1956						
Aug. 16	[1] 80. 2	85. 8	24. 4	0	24. 4	8. 1
1957						
June 2	[1] 80. 5	85. 6	20. 2	0	20. 2	7. 2
July 24	[1] 80. 5	86. 5	28. 2	0	28. 2	10. 1
Aug. 5–6	[1] 80. 5	90. 6	86. 2	0	86. 2	30. 8
Aug. 12	[1] 80. 5	83. 9	4. 2	0	4. 2	1. 5
Aug. 18	[1] 80. 5	83. 6	3. 6	0	3. 6	1. 3
Aug. 24	[1] 80. 5	84. 0	4. 9	0	4. 9	1. 7
Aug. 29	[1] 80. 5	84. 0	4. 9	0	4. 9	1. 7
Oct. 12	[1] 80. 5	85. 0	10. 0	0	10. 0	3. 6
Total			162. 2	0	162. 2	57. 9
1958 [2]						
1959						
June 21	[1] 82. 6	84. 4	4. 3	0	4. 3	1. 5
Aug. 14	[1] 82. 6	85. 0	7. 1	0	7. 1	2. 5
Aug. 24	82. 8	84. 3	3. 6	0	3. 6	1. 3
Oct. 13	[1] 82. 6	84. 5	4. 7	0	4. 7	1. 7
Oct. 30	[1] 82. 6	84. 3	4. 5	0	4. 5	1. 6
Total			24. 2	0	24. 2	8. 6
1960						
Oct. 16–18	[1] 82. 6	83. 4	. 8	0	. 8	. 3

[1] Reservoir dry at beginning of flow. Elevation before inflow is the elevation of the low point of the reservoir.
[2] No flow.

TABLE 4.—*Storm runoff measured in reservoirs in Cornfield Wash*—Continued

Reservoir 12

Drainage area.—7.33 sq mi April 1951 to September 1956 and 7.07 sq mi thereafter.
Records available.—July 1951 to October 1960.
Gage.—Crest-stage gage April 1951 to May 1959 and water-stage recorder thereafter. Datum of gage is about 6,600 ft above mean sea level.
Runoff and discharge determinations.—Contents of reservoir and volume of inflow and outflow computed from a stage-capacity curve of the reservoir.
Capacity.—Original, 323.6 acre-ft, July 1951; 127.5 acre-ft, October 1960.
Remarks.—Records poor.

Date of flow	Gage height (feet)		Inflow stored (acre-ft)	Spill (acre-ft)	Inflow	
	Before inflow	After inflow			Total (acre-ft)	Acre-ft per sq mi
1956						
July 28	[1] 46. 0	47. 7	7. 5	0	7. 5	1. 1
Aug. 16	46. 8	48. 2	9. 2	0	9. 2	1. 3
Total			16. 7	0	16. 7	2. 4
1957						
June 2	[1] 46. 1	53. 9	101. 2	0	101. 2	12. 2
July 16	46. 8	47. 2	1. 6	0	1. 6	. 2
July 22	46. 9	47. 7	2. 7	0	2. 7	. 4
July 24	47. 6	53. 7	84. 8	0	84. 8	11. 1
Aug. 6	49. 6	57. 3	107. 0	85	192. 0	25. 3
Aug. 12	48. 2	49. 2	6. 7	0	6. 7	. 1
Aug. 30	47. 7	48. 1	2. 2	0	2. 2	. 3
Oct. 12	47. 7	51. 5	32. 9	0	32. 9	4. 7
Total			339. 1	85	424. 1	54. 3
1958 [2]						
1959						
Aug. 14	[1] 47. 3	50. 3	21. 5	0	21. 5	2. 4
Aug. 24	[1] 47. 3	48. 5	5. 0	0	5. 0	. 1
Oct. 3	[1] 47. 3	47. 9	1. 0	0	1. 0	. 1
Oct. 30	[1] 47. 3	48. 9	7. 5	0	7. 5	. 3
Total			35. 0	0	35. 0	3. 0
1960						
Oct. 16–18	[1] 47. 3	48. 6	6. 0	0	6. 0	. 8

[1] Reservoir dry at beginning of flow. Elevation before inflow is the elevation of the low point of the reservoir.
[2] No flow.

219–285 O—66——6

TABLE 4.—*Storm runoff measured in reservoirs in Cornfield Wash*—Continued

Reservoir 13

Drainage area.—0.33 sq mi.
Records available.—July 1951 to October 1960.
Gage.—Crest-stage gage. Datum of gage is about 6,600 ft above mean sea level.
Runoff and discharge determinations.—Contents of reservoir and volume of inflow and outflow computed from a stage-capacity curve of the reservoir.
Capacity.—Original, 7.4 acre-ft, April 1951; 0.3 acre-ft, October 1960.
Remarks.—Records poor.

Date of flow	Gage height (feet)		Inflow stored (acre-ft)	Spill (acre-ft)	Inflow	
	Before inflow	After inflow			Total (acre-ft)	Acre-ft per sq mi
1956						
July 28	[1] 50. 0	53. 0	1. 8	1. 8	3. 6	10. 9
Aug. 16	50. 3	50. 9	. 4	0	. 4	1. 2
Total			2. 2	1. 8	4. 0	12. 1
1957						
June 2	[1] 50. 0	54. 4	1. 8	14. 5	16. 3	49. 4
July 22	[1] 50. 0	51. 4	1. 0	0	1. 0	3. 0
July 24	50. 9	53. 6	1. 8	4. 1	5. 9	17. 9
Aug. 5	50. 6	51. 7	. 9	0	. 9	2. 7
Aug. 6	51. 6	53. 9	. 5	10. 0	10. 5	31. 8
Aug. 12	51. 9	53. 0	. 2	6. 6	6. 8	20. 6
Aug. 16	52. 0	52. 7	. 2	1. 6	1. 8	5. 5
Aug. 24	51. 7	52. 4	. 4	. 7	1. 1	3. 3
Aug. 31	51. 8	52. 7	. 3	1. 7	2. 0	6. 1
Oct. 12	50. 8	53. 4	1. 8	5. 3	7. 1	21. 5
Oct. 20	51. 8	52. 4	. 3	. 4	. 7	2. 1
Total			9. 2	44. 9	54. 1	163. 9
1958 [2]						
1959						
Aug. 14	[1] 50. 8	53. 6	. 3	6. 8	7. 1	21. 5
Aug. 24	51. 3	53. 5	. 1	6. 1	6. 2	18. 8
Oct. 3	[1] 50. 8	52. 7	. 3	1. 8	2. 1	6. 4
Oct. 30	[1] 50. 8	53. 6	. 3	7. 2	7. 5	22. 7
Total			1. 0	21. 9	22. 9	69. 4
1960						
Oct. 16–18	[1] 50. 9	51. 5	. 1	0	. 1	. 3

[1] Reservoir dry at beginning of inflow. Elevation before inflow is the elevation of the low point of the reservoir.
[2] No flow.

TABLE 4.—*Storm runoff measured in reservoirs in Cornfield Wash*—Continued

Reservoir 15

Drainage area.—1.04 sq mi.
Records available.—July 1953 to October 1960.
Gage.—Crest-stage gage. Datum of gage is about 6,690 ft above mean sea level.
Runoff and discharge determinations.—Contents of reservoir and volume of inflow and outflow computed from a stage-capacity curve of the reservoir.
Capacity.—Original, 17.9 acre-ft, December 1953; 17.8 acre-ft, October 1960.
Remarks.—Records fair.

Date of flow	Gage height (feet)		Inflow stored (acre-ft)	Spill (acre-ft)	Inflow	
	Before inflow	After inflow			Total (acre-ft)	Acre-ft per sq mi
1956						
July 19	[1] 56.3	58.8	1.0	0	1.0	1.0
Aug. 16	[1] 56.3	58.2	.5	0	.5	.5
Total			1.5	0	1.5	1.5
1957						
June 2	[1] 56.3	58.4	.5	0	.5	.5
July 24	[1] 56.3	48.2	.4	0	.4	.4
Aug. 5	[1] 56.3	60.1	2.5	0	2.5	2.4
Aug. 6	56.8	57.8	.2	0	.2	.2
Aug. 12	[1] 56.3	57.4	.1	0	.1	.1
Aug. 16	[1] 56.3	59.4	1.5	0	1.5	1.4
Aug. 24	[1] 56.3	57.4	.1	0	.1	.1
Oct. 12	[1] 56.3	59.5	1.5	0	1.5	1.4
Total			6.8	0	6.8	6.5
1958 [2]						
1959						
Aug. 14	[1] 56.3	57.8	.2	0	.2	.2
Aug. 24	[1] 56.3	58.5	.6	0	.6	.6
Total			.8	0	.8	.8
1960						
Oct. 16–18	56.9	70.4	.1	0	.1	.1

[1] Reservoir dry at beginning of flow. Elevation before inflow is the elevation of the low point of the reservoir.
[2] No flow.

TABLE 4.—*Storm runoff measured in reservoirs in Cornfield Wash*—Continued

Reservoir 16

Drainage area.—0.55 sq mi.
Records available.—July 1953 to July 1954 and July 1955 to October 1960.
Gage.—Crest-stage gage. Datum of gage is about 6,650 ft above mean sea level.
Runoff and discharge determinations.—Contents of reservoir and volume of inflow and outflow computed from a stage-capacity curve of the reservoir.
Capacity.—Original, 28.9 acre-ft, April 1955; 26.8 acre-ft, October 1960.
Remarks.—Records fair.

Date of flow	Gage height (feet)		Inflow stored (acre-ft)	Spill (acre-ft)	Inflow	
	Before inflow	After inflow			Total (acre-ft)	Acre-ft per sq mi
1956						
July 19	[1] 55.5	59.8	3.0	0	3.0	5.5
July 28	59.1	59.4	.3	0	.3	.5
Aug. 16	58.0	60.7	3.1	0	3.1	5.6
Total			6.4	0	6.4	11.6
1957						
June 2	[1] 55.9	63.6	9.6	0	9.6	17.5
July 22	59.2	59.7	.6	0	.6	1.1
July 24	59.6	62.2	3.9	0	3.9	7.1
Aug. 5	60.3	64.0	6.8	0	6.8	12.4
Aug. 6	63.1	66.4	9.8	0	9.8	17.8
Aug. 16	60.4	64.5	7.9	0	7.9	14.4
Aug. 24	60.5	62.0	2.4	0	2.4	4.4
Aug. 31	60.4	61.8	2.1	0	2.1	3.8
Oct. 12	59.5	63.0	6.3	0	6.3	11.5
Total			49.4	0	49.4	89.8
1958 [2]						
1959						
Aug. 14	[1] 56.5	63.8	8.7	0	8.7	15.8
Aug. 19	60.9	61.0	.1	0	.1	.2
Aug. 24	60.7	63.3	4.2	0	4.2	7.6
Oct. 3	59.3	61.6	2.9	0	2.9	5.3
Oct. 30	59.1	60.0	1.1	0	1.1	2.0
Total			17.0	0	17.0	30.9
1960						
Mar. 5–6	[1] 56.7	61.7	4.2	0	4.2	7.6
Aug. 23	[1] 56.7	58.5	.5	0	.5	.9
Oct. 16–18	[1] 56.7	61.2	3.4	0	3.4	6.2
Total			8.1	0	8.1	14.7

[1] Reservoir dry at beginning of flow. Elevation before inflow is the elevation of the low point of th reservoir.
[2] No flow.

TABLE 4.—*Storm runoff measured in reservoirs, in Cornfield Wash*—Continued

Reservoir 17

Drainage area.—0.59 sq mi.
Records available.—July 1954 and July 1955 to October 1960.
Gage.—Crest-stage gage. Datum of gage is about 6,750 ft above mean sea level.
Runoff and discharge determinations.—Contents of reservoir and volume of inflow and outflow computed from a stage-capacity curve of the reservoir.
Capacity.—Original, 18.3 acre-ft, April 1955; 16.6 acre-ft, October 1960.
Remarks.—Records fair.

Date of flow	Gage height (feet)		Inflow stored (acre-ft)	Spill (acre-ft)	Inflow	
	Before inflow	After inflow			Total (acre-ft)	Acre-ft per sq mi
1956						
July 28	[1] 61.8	62.2	0.1	0	0.1	0.2
Aug. 16	[1] 61.8	63.9	.5	0	.5	.8
Total			.6	0	.6	1.0
1957						
June 2	[1] 61.8	64.1	.6	0	.6	1.0
July 24	62.0	65.4	1.6	0	1.6	2.7
Aug. 5	64.6	66.7	1.6	0	1.6	2.7
Aug. 6	65.1	69.1	4.6	0	4.6	7.8
Aug. 12	64.7	65.5	.6	0	.6	1.0
Aug. 16	64.8	65.1	.2	0	.2	.3
Aug. 24	64.8	65.9	.8	0	.8	1.4
Aug. 31	64.9	65.1	.2	0	.2	.3
Oct. 12	63.9	66.3	1.7	0	1.7	2.9
Total			11.9	0	11.9	20.2
1958 [2]						
1959						
Aug. 14	[1] 62.8	65.9	1.7	0	1.7	2.9
Aug. 19	64.8	65.2	.3	0	.3	.5
Aug. 24	64.9	65.9	.7	0	.7	1.2
Oct. 3	63.5	64.1	.3	0	.3	.5
Oct. 30	63.1	65.0	1.3	0	1.3	2.2
Total			4.3	0	4.3	7.3
1960						
Mar. 5–6	[1] 63.0	65.0	.9	0	.9	1.5
Aug. 23	[1] 63.0	65.0	.9	0	.9	1.5
Oct. 16	[1] 63.0	65.4	1.2	0	1.2	2.0
Total			3.0	0	3.0	5.1

[1] Reservoir dry at beginning of flow. Elevation before inflow is the elevation of the low point of the reservoir.
[2] No flow.

TABLE 4.—*Storm runoff measured in reservoirs in Cornfield Wash*—Continued

Reservoir 18

Drainage area.—0.02 sq mi.
Records available.—June 1957 to October 1960.
Gage.—Crest-stage gage. Datum of gage is about 6,630 ft above mean sea level.
Runoff and discharge determinations.—Contents of reservoir and volume of inflow and outflow computed from a stage-capacity curve of the reservoir.
Capacity.—Original, 4.4 acre-ft, April 1957; 4.4 acre-ft, October 1960.
Remarks.—Records fair.

Date of flow	Gage height (feet)		Inflow stored (acre-ft)	Spill (acre-ft)	Inflow	
	Before inflow	After inflow			Total (acre-ft)	Acre-ft per sq mi
1957						
July 24	4.4	6.8	0.2	0	0.2	10.0
Aug. 5	5.5	8.3	.5	0	.5	25.0
Aug. 12	7.2	8.0	.2	0	.2	10.0
Aug. 31	6.3	6.6	.1	0	.1	5.0
Oct. 20	[1] 4.4	7.4	.3	0	.3	15.0
Total			1.3	0	1.3	65.0
1958 [2]						
1959						
Aug. 14	[1] 4.8	6.1	.1	0	.1	5.0
1960 [2]						

[1] Reservoir dry at beginning of flow. Elevation before inflow is the elevation of the low point of the reservoir.
[2] No flow.

TABLE 4.—*Storm runoff measured in reservoirs in Cornfield Wash*—Continued

Reservoir 19

Drainage area.—0.18 sq mi.
Records available.—June 1957 to October 1960.
Gage.—Crest-stage gage. Datum of gage is about 6,560 ft above mean sea level.
Runoff and discharge determinations.—Contents of reservoir and volume of inflow and outflow computed from a stage-capacity curve of the reservoir.
Capacity.—Original, 13.4 acre-ft, June 1957; 13.4 acre-ft, October 1960.
Remarks.—Records fair.

Date of flow	Gage height (feet)		Inflow stored (acre-ft)	Spill (acre-ft)	Inflow	
	Before inflow	After inflow			Total (acre-ft)	Acre-ft per sq mi
1957						
June 2	[1] 9.5	15.3	1.4	0	1.4	7.8
July 22	[1] 9.5	10.3	.1	0	.1	.6
July 24	10.2	18.5	3.3	0	3.3	18.3
Aug. 5	15.0	22.5	6.1	0	6.1	33.9
Aug. 12	20.2	22.4	2.6	0	2.6	14.4
Aug. 24	18.2	19.3	.8	0	.8	4.4
Aug. 31	17.5	18.8	.9	0	.9	5.0
Total			15.2	0	15.2	84.4
1958 [2]						
1959						
June 25	[1] 11.0	13.8	.6	0	.6	3.3
Aug. 14	[1] 11.0	15.2	1.0	0	1.0	5.6
Total			1.6	0	1.6	8.9
1960 [2]						

[1] Reservoir dry at beginning of flow. Elevation before inflow is the elevation of the low point of the reservoir.
[2] No flow.

TABLE 4.—*Storm runoff measured in reservoirs in Cornfield Wash*—Continued

Reservoir 20

Drainage area.—0.26 sq mi.
Records available.—June 1957 to October 1960.
Gage.—Crest-stage gage. Datum of gage is about 6,560 ft above mean sea level.
Runoff and discharge determinations.—Contents of reservoir and volume of inflow and outflow computed from a stage-capacity curve of the reservoir.
Capacity.—Original, 28.1 acre-ft, June 1957; 26.2 acre-ft, October 1960.
Remarks.—Records fair.

Date of flow	Gage height (feet)		Inflow stored (acre-ft)	Spill (acre-ft)	Inflow	
	Before inflow	After inflow			Total (acre-ft)	Acre-ft per sq mi
1957						
June 2	[1] 4.2	12.6	3.5	0	3.5	13.5
July 24	[1] 4.2	12.6	3.6	0	3.6	13.8
Aug. 5	8.0	13.6	4.2	0	4.2	16.2
Aug. 12	7.4	12.2	2.7	0	2.7	10.4
Aug. 31	6.3	7.7	.4	0	.4	1.5
Oct. 12	6.3	9.2	1.0	0	1.0	3.8
Oct. 20	7.0	8.4	.3	0	.3	1.2
Total			15.7	0	15.7	60.4
1958 [2]						
1959						
Aug. 14	[1] 6.0	11.1	1.4	0	1.4	5.4
1960						
Oct. 16–18	6.2	9.1	.3	0	.3	1.2

[1] Reservoir dry at beginning of flow. Elevation before inflow is the elevation of the low point of the reservoir.
[2] No flow.

Table 4—Storm runoff measured in reservoirs in Cornfield Wash—Continued

Reservoir 21

Drainage area.—0.03 sq mi.
Records available.—June 1957 to October 1960.
Gage.—Crest-stage gage. Datum of gage is about 6,590 ft above mean sea level.
Runoff and discharge determinations.—Contents of reservoir and volume of inflow and outflow computed from a stage-capacity curve of the reservoir.
Capacity.—Original, 8.2 acre-ft, October 1958; same, October 1960.
Remarks.—Records fair. No inflow records in 1957; runoff estimated to be the same as that for watershed 11.

Date of flow	Gage height (feet)		Inflow stored (acre-ft)	Spill (acre-ft)	Inflow	
	Before inflow	After inflow			Total (acre-ft)	Acre-ft per sq mi
1957						
	--------	--------	1.7	0	1.7	56.7
1958 [1]						
1959						
Aug. 14	[2] 33.2	34.9	0.1	0	.1	3.3
1960 [1]						

[1] No flow.
[2] Reservoir dry at beginning of flow. Elevation before inflow is the elevation of the low point of the reservoir.

Table 5.—*Seasonal runoff and annual sediment deposition, 1951–60*

Reservoir	Drainage area (sq mi)	1951				1952				1953				1954				1955			
		Runoff		Sediment		Runoff		Sediment [1]		Runoff		Sediment		Runoff		Sediment		Runoff		Sediment	
		Acre-ft	Acre-ft per sq mi	Acre-ft	Acre-ft per sq mi	Acre-ft	Acre-ft per sq mi	Acre-ft	Acre-ft per sq mi	Acre-ft	Acre-ft per sq mi	Acre-ft	Acre-ft per sq mi	Acre-ft	Acre-ft per sq mi	Acre-ft	Acre-ft per sq mi	Acre-ft	Acre-ft per sq mi	Acre-ft	Acre-ft per sq mi
1	0.29	20.9	72.1	0.8	2.8	14.1	48.6	0.5	1.7	15.7	54.1	4.2	14.5	20.2	69.7	1.0	3.4	39.1	134.8	4.3	14.8
2	.87	21.0	24.1	2.0	2.3	10.9	12.5	.1	.1	29.0	33.3	4.4	5.1	23.9	27.5	.1	.1	28.2	32.4	2.4	2.8
3	.25	5.3	21.2	.1	.4	8.7	34.8	.7	2.8	9.1	36.4	1.0	4.0	18.2	72.8	.5	2.0	11.6	46.4	.4	1.6
4	1.18	11.0	9.3	0	0	32.8	27.8	.2	.2	24.6	20.8	2.0	1.7	42.7	36.2	1.4	1.2	17.0	14.4	0	0
5	1.04	9.6	9.2	.6	.6	27.8	26.7	1.5	1.4	6.5	6.2	1.1	1.1	52.5	50.5	.8	.8	18.4	17.7	1.2	1.2
6	2.77	38.0	13.7	3.0	1.1	112.4	40.6	2.8	1.0	[2] 67.7	24.4	8.7	3.1	182.2	[3] 73.7	14.0	5.1	124.9	57.3	8.7	4.0
7	1.07	26.0	24.3	2.5	2.3	27.6	25.8	.2	.2	[4] 15.4	29.6	2.0	3.8	68.8	[3] 66.2	3.5	3.3	38.7	74.4	1.2	2.3
9	.09	4.2	46.7	.4	4.4	8.8	97.8	.1	1.1	4.4	48.9	.2	2.2	13.9	154.4	.7	7.8	9.5	105.5	.4	4.4
10	3.05	48.0	15.7	1.7	.6	105.8	34.7	.9	.3	[5] 17.9	8.9	3.9	1.9	106.9	53.2	0	0	97.5	48.5	5.0	2.5
11	3.03	118.0	38.9	15.0	5.0	213.3	70.4	6.5	2.1	99.6	32.9	10.7	3.6	118.1	39.0	13.8	4.6	220.0	72.6	13.5	4.4
12	7.33	271.0	37.0	22.0	3.0	[6] 275.0	37.5	13.2	1.8	370.0	50.5	50.1	6.8	459.0	62.6	43.6	5.9	358.5	48.9	32.3	4.4
13	.33	6.6	20.0	.5	1.5	9.3	28.2	.2	.6	12.5	37.9	4.2	12.7	11.7	35.4	1.0	3.0	11.1	33.6	1.2	3.6
15	1.04	------	------	------	------	------	------	------	------	[7] .7	.7	0	0	6.5	.6	0	0	2.5	2.4	0	0
16	.55	------	------	------	------	------	------	------	------	[7] 9.3	16.9	------	------	[8] 22.8	------	------	------	34.6	62.9	1.3	2.4
17	.59	------	------	------	------	------	------	------	------	------	------	------	------	[8] 21.9	------	------	------	28.3	48.0	.7	1.2
18	.02	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------
19	.18	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------
20	.26	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------
21	.03	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------
Total	21.30	579.6	27.2	48.6	2.3	846.5	39.7	26.9	1.3	682.4	32.0	92.5	4.3	1,169.3	54.9	80.4	3.8	1,039.9	48.8	72.6	3.4

		1956				1957				1958				1959				1960			
1	0.29	7.2	24.9	0	0	30.3	104.5	3.0	10.3	0	0	0	0	6.1	21.0	0	0	12.4	42.7	0	0
2	.87	.9	1.0	0	0	45.9	52.8	.8	.9	0	0	0	0	7.0	8.0	0	0	6.3	7.2	0	0
3	.25	1.6	6.4	0	0	21.6	86.4	1.1	4.4	0	0	0	0	4.9	19.6	0	0	2.1	8.4	0	0
4	1.18	0	0	0	0	33.8	28.6	1.2	1.0	0	0	0	0	10.1	8.6	0	0	1.2	1.0	0	0
5	1.04	1.2	1.2	0	0	53.6	51.5	1.2	1.2	0	0	0	0	11.4	11.0	0	0	13.3	12.8	0	0
6	2.77	0	0	0	0	97.2	44.6	3.3	1.5	0	0	0	0	11.6	5.3	0	0	13.1	4.8	0	0
7	1.07	1.7	3.3	0	0	40.5	77.9	.4	.8	0	0	0	0	14.3	27.5	1.1	2.1	[9] 4.3	8.3	0	0
9	.09	1.2	13.3	0	0	3.9	43.3	0	0	0	0	0	0	2.5	27.8	0	0	.1	1.1	0	0
10	3.05	4.6	2.3	0	0	48.3	24.0	.5	.2	0	0	0	0	24.3	12.1	0	0	4.0	2.0	0	0
11	3.03	24.4	8.1	3.9	1.3	[10] 162.2	57.9	12.4	4.1	0	0	0	0	24.2	8.6	2.5	.9	.8	.3	0	0
12	7.33	16.7	2.4	0	0	[11] 384.1	54.3	51.6	7.0	0	0	0	0	20.9	3.0	0	0	6.0	.8	0	0
13	.33	4.0	12.1	.1	.3	54.1	163.9	1.5	4.5	0	0	0	0	22.9	69.4	.8	2.4	.1	.3	0	0
15	1.04	1.5	1.4	0	0	6.8	6.5	0	0	0	0	0	0	.8	.8	0	0	.1	.1	0	0
16	.55	6.4	11.6	.1	.2	49.4	89.8	1.0	1.8	0	0	0	0	17.0	30.9	.8	1.5	8.1	14.7	0	0
17	.59	.6	1.0	0	0	11.9	20.2	.2	.3	0	0	0	0	4.3	7.3	0	0	3.0	5.1	0	0
18	.02	------	------	------	------	1.3	65.0	0	0	0	0	0	0	.1	5.0	0	0	0	0	0	0
19	.18	------	------	------	------	15.2	84.4	.4	------	------	------	------	------	1.6	8.9	0	0	0	0	0	0
20	.26	------	------	------	------	15.7	60.4	.8	------	------	------	------	------	1.4	5.4	.2	1.1	.3	1.2	0	0
21	.03	------	------	------	------	[12] 1.7	56.7	------	------	0	0	0	0	.1	3.3	0	0	0	0	0	0
Total	21.30	72.0	3.4	4.1	.2	1,077.5	50.6	79.4	3.7	0	0	0	0	185.5	8.7	5.4	.3	75.2	3.5	0	0

[1] Complete reservoir surveys were not made in 1952; surveys were confined to lowest parts of reservoirs, hence, sediment figures may be slightly low.
[2] Drainage area of reservoir 6 reduced from 2.77 to 2.18 sq mi by construction of dam 17, May 1954; dam breached July 1954; reconstructed May 1955.
[3] Upstream reservoir breached; unit inflows are estimated on the basis of records for nearby basins.
[4] Drainage area of reservoir 7 reduced from 1.07 to 0.52 sq mi by construction of dam 16, April 1953; dam breached July 1954; reconstructed May 1955.
[5] Drainage area of reservoir 10 reduced from 3.05 to 2.01 sq mi by construction of dam 15, May 1953.
[6] No record; runoff estimated to be the same as in remainder of basin.
[7] Highest flow of season; lesser flows not recorded.
[8] Runoff observed prior to failure of dam in July.
[9] Inflow partly estimated.
[10] Drainage area of reservoir 11 reduced from 3.03 to 2.80 sq mi by construction of dams 18, 19, and 21, October 1956.
[11] Drainage area of reservoir 12 reduced from 7.33 to 7.07 sq mi by construction of dam 20, October 1956.
[12] No record; runoff estimated to be the same as in watershed 11.

were selected for study—4 from reservoir 5, 7 from reservoir 6, and 2 from reservoir 7. Table 6 shows that the percent difference between computed spill and gaged spill is relatively large for individual storms. On the other hand, the cumulative computed spill is about equal to the cumulative gaged spill. The relatively large difference between computed and gaged spill for individual storms may be due to the following: (1) The runoff producing rainfall on watershed 2 was not similar to that of watersheds 5–7; (2) the basin characteristics that control the shape of the runoff hydrographs for watershed 2 are not similar to those of watersheds 5–7; and (3) the gaged spill may be in error.

The percentage spill compared to total inflow is shown in table 7. The comparison shows that the spill constitutes a large percent of the total inflow to several reservoirs. The storage capacity of

TABLE 6.—*Comparison of computed spill with gaged spill*

Spill			Difference (percent of gaged spill)
Date	Gaged (acre-ft)	Computed [1] (acre-ft)	
Reservoir 5			
July 27, 1955	5.7	8.5	49
Aug. 4, 1955	2.3	1.4	39
Aug. 6, 1955	2.3	1.5	35
Aug. 17, 1955	1.5	1.4	7
Total 1955	11.8	12.8	8
Reservoir 6			
July 30, 1957	11.6	8.9	23
Aug. 5, 1957	18.3	26.6	45
Aug. 6, 1957	54.0	63.4	17
Aug. 12, 1957	8.7	4.5	48
Aug. 16, 1957	6.1	4.1	33
Aug. 24, 1957	12.4	8.2	34
Do	6.5	5.9	9
Total 1957	117.5	121.6	3
Reservoir 7			
Aug. 6, 1957	11.0	7.8	29
Aug. 14, 1959	2.1	2.3	10
Total 1957, 1959	13.1	10.2	22
Grand total	142.4	144.6	1

[1] Computed from the equation: $V=S\left[1+\frac{CQ\sqrt{A}}{S+S_1}\right]$.

TABLE 7.—*Spillage from reservoirs in the Cornfield Wash basin*

Reservoir	Spill (percent of total inflow)		
	1951-55	1956-60	1951-60
1	10.5	17.0	12.7
2	[1] 0	[1] 0	0
3	45.2	49.3	46.7
4	10.9	0	8.1
5	53.9	69.3	59.5
6	51.3	[1] 68.8	55.3
7	37.4	[1] 10.0	27.7
9	16.4	0	13.8
10	10.9	0	8.8
11	0	0	0
12	9.1	17.0	11.0
13	32.3	84.6	38.1
Composite	20.8	24.9	21.9

[1] Recording gage at reservoir.

reservoirs 1, 2, 4, and 9–12 was sufficient for most of the inflow; therefore, the accuracy of the inflow records for these reservoirs is considered to be fair to good. The accuracy of the inflow records for individual storm periods for the remaining reservoirs is considered poor, but records of seasonal inflow are considered fair.

MAGNITUDE AND FREQUENCY

A study was made of the largest consecutive 3-day runoff for reservoirs 1–13 to determine what percent of the annual flow occurred during the maximum storm. The comparison was made by dividing the sum of the largest annual floods (3-day volume) for the 1951–60 period by the total runoff for the same period. The comparison indicates that about 55 percent of the total seasonal runoff occurs in one major storm each year.

Another study was made of the largest annual flood volumes for reservoirs 1–13 to determine their probable range. A mean annual flood-frequency curve was prepared for each reservoir by plotting the flood volume against its recurrence interval on frequency charts. The recurrence interval was computed by means of the formula:

$$T=\frac{N+1}{M},$$

in which

T=recurrence interval, in years;
N=number of years of record; and
M=order number of the flood, with the largest flood assigned No. 1.

The probable range of the mean annual flood was taken from the frequency curve with the upper and lower limits at recurrence intervals of 3.3 and 1.5 years. The mean flood ranges are plotted against drainage areas on figure 9. The relation of the greatest consecutive 3-day runoff to the size of the drainage area is also shown in figure 9.

RELATION TO PRECIPITATION

A plot of the seasonal composite runoff of the Cornfield Wash basin against the seasonal rainfall (fig. 10) indicates that a significant change, presumably due to decreased rainfall intensity, in the runoff-rainfall relationship occurred after 1956 when there was about 60 percent less runoff for the same amount of rainfall.

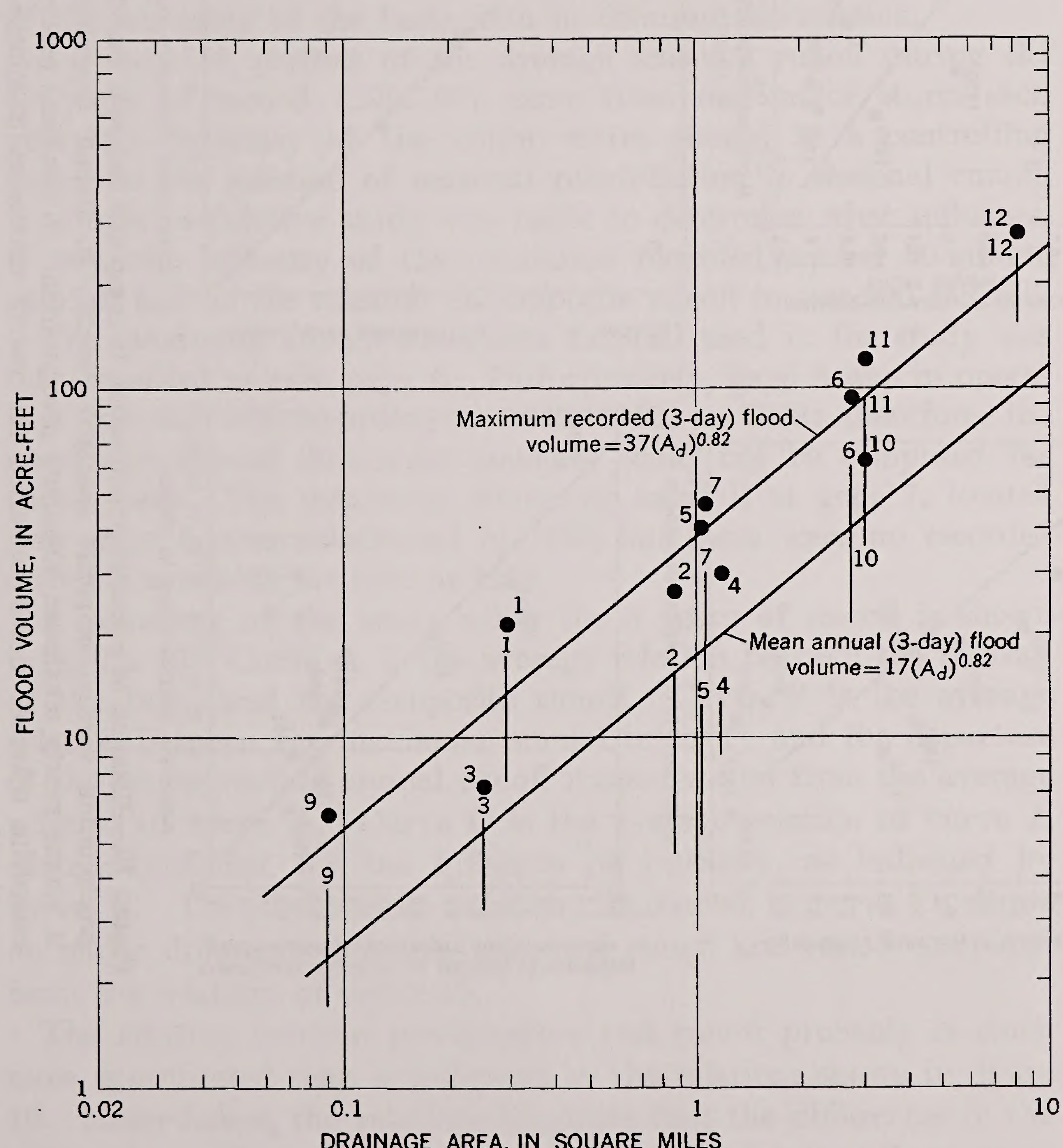

FIGURE 9.—Relation of maximum 3-day flood volume to size of drainage basin for 1951–60. The vertical lines represent the probable range of mean annual flood volumes at reservoirs 1–13.

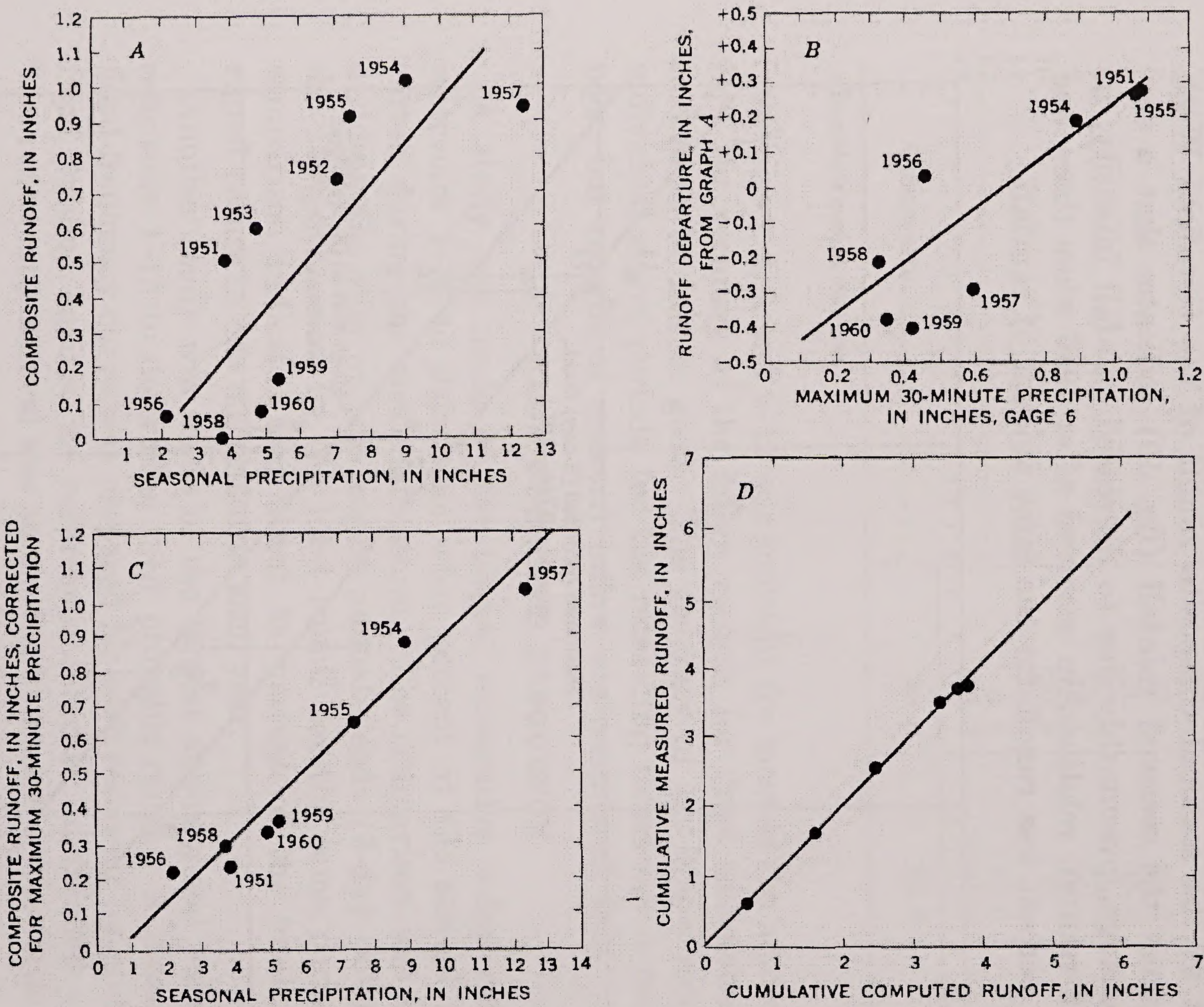

FIGURE 10.—Relation of seasonal precipitation to composite seasonal runoff. *A*. Seasonal precipitation versus composite seasonal runoff. *B*. Runoff departure from graph *A* versus yearly maximum 30-minute precipitation. *C*. Seasonal precipitation versus composite seasonal runoff corrected for yearly maximum 30-minute precipitation. *D*. Double-mass diagram of computed runoff versus measured runoff.

The most logical approach toward determining why there was a reduced ratio of runoff to rainfall in the Cornfield Wash basin after 1956 would be to analyze the runoff-rainfall relation for each watershed by storms. This would mean that an average precipitation amount for individual storms would have to be determined. Rainfall intensities and storm runoff also would have to be known. As noted in the section on study procedure, the number of rain gages in operation during much of the study was not adequate to define the rainfall amounts and intensities. Also, the accuracy of the storm runoff data for many of the watersheds in the Cornfield Wash basin is poor. Therefore, a study of the runoff-precipitation ratio for each storm was not pursued beyond a preliminary check of the adequacy of the basic data in defining the relation.

As about 55 percent of the average seasonal runoff during the 10 years of record (1951–60) came from one major storm each year, the intensity of the major storm should be a controlling factor in the relation of seasonal precipitation to seasonal runoff. A simple correlative study was made to determine what influence, if any, the intensity of the maximum recorded annual 30-minute rainfall had on the relation of composite runoff to seasonal rainfall.

The maximum annual 30-minute rainfall used in the study was that recorded at rain gage 6. Unfortunately, gage 6 was in operation but was not recording in 1952, 1953, or 1958; therefore, the maximum annual 30-minute amounts could not be computed for those years. The maximum 30-minute rainfall at gage 7, located near gage 6, was substituted in 1958, but there were no recorded amounts available for 1952 or 1953.

A summary of the study using the 8 years of record is shown in figure 10. Curve A is the average relation between the rainfall of the basin and the composite runoff. Curve B is the average relation between the maximum annual intensity and the departure of the corresponding annual runoff measurements from the average relation of curve A. Curve C is the average relation of curve A after adjustment for the influence of intensity, as indicated by curve B. The double-mass relation, illustrated in curve D, shows no major differences between measured runoff and runoff computed from the relations of figure 10.

The relation between precipitation and runoff probably is much more complicated than is indicated by the relations shown in figure 10. Nevertheless, the relations illustrate that the differences in the ratios of runoff to precipitation are primarily due to differences in rainfall intensities. It can be concluded that the percentage of precipitation that runs off during a major thunderstorm is rela-

tively high for the Cornfield Wash basin; therefore, the ratio of seasonal runoff to seasonal precipitation is relatively high for those years in which runoff comes mainly from major thunderstorms. Conversely, the ratio of seasonal runoff to seasonal precipitation is relatively small when the runoff comes primarily from precipitation of low intensity.

RELATION TO BASIN CHARACTERISTICS

Differences in basin characteristics probably are more influential than differences in precipitation in causing the variation in average seasonal runoff from the small watersheds of the Cornfield Wash basin. Large runoff yield from a small watershed occurs when a local thunderstorm of rare occurrence is centered over the watershed. The large runoff yield would cause the short-term average seasonal yield to be large in relation to the long-term average. Conversely, a short-term average seasonal runoff may be relatively low compared to a long-term average. The seasonal runoff records, of 10-year duration, used in the average runoff computation for the Cornfield Wash study probably are of sufficient length to eliminate the controlling effect of runoff from any one storm during that period. Therefore, basin characteristics should be given the most consideration in explaining the relatively large variation in average seasonal runoff for the watersheds of the Cornfield Wash basin.

The readily measurable basin characteristics used in this study are (1) area, (2) land slope, (3) length of longest watercourse, (4) distance along the longest watercourse from the gaging site to a point opposite the center of the drainage area, and (5) channel slope. Other basin characteristics, which were not studied, that may have an appreciable influence on the runoff are (1) channel density, (2) type of soil, (3) infiltration rates, and (4) the kinds and amounts of vegetation.

The area (A_d) used is simply the horizontal projection of the land surface from which runoff into the surface channels above the gaging station occurs. Area is the primary basin characteristic used in this study.

Land slope (S_L), or mean basin slope, was determined from topographic maps by the intersections-line method described by Horton (1932). Because land slope influences the rate at which water drains from a basin, runoff should vary with land slope.

The most commonly used basin-shape factors are L_{ca} and the product of L times L_{ca} to some power, where L is the length along the longest watercourse, and L_{ca} is the distance along the longest watercourse to a point opposite the centroid of the drainage area (Golding and Low,

1960). Because the time necessary for water to drain from a basin is related to basin shape, L and L_{ca} should be important factors in any investigation in which variations in average runoff are analyzed.

There are several ways of expressing channel slope. The merits of each are fully discussed by Golding and Low (1960). The channel slope in this report is the slope of an equivalent stream having the same travel time and length. Equivalent slope (S_{st}) was computed by a method described by Taylor and Schwarz (1952). The equation for the equivalent slope is as follows:

$$S_{st}=\left(\frac{P}{\Sigma\frac{1}{\sqrt{S_a}}}\right)^2,$$

in which

P=the number of equal reaches into which the channel has been divided (often 10); and

S_a=the average slope of each such reach measured as the change of elevation over the reach divided by its length.

The first comparison using runoff as a variable was that of average seasonal runoff for 1951–60 in the Cornfield Wash watersheds with the size of the drainage area. The relation is shown in figure 11. The line drawn through the points is defined by the equation:

$$R_a=31.0(A_d)^{0.82},$$

in which

R_a=average seasonal runoff in acre-feet for 1951–60.

The coefficient of correlation [2] is 0.944, and the standard error of estimate is 0.186 log unit.

By multiple-correlation analysis, average seasonal runoff was found to be best defined by the equation:

$$R_a=10{,}168\ (A_d)^{0.82}(S_L)^{2.235}.$$

The standard error of estimate is 0.098 log unit, and the coefficient of correlation is 0.98. A comparison of measured runoff with runoff computed from the equation given above is shown in figure 12.

The measured runoff of watershed 7 is considerably greater than the computed runoff (fig. 12). The most logical explanation for this

[2] The coefficient of correlations and standard errors of estimate in this report are determined graphically.

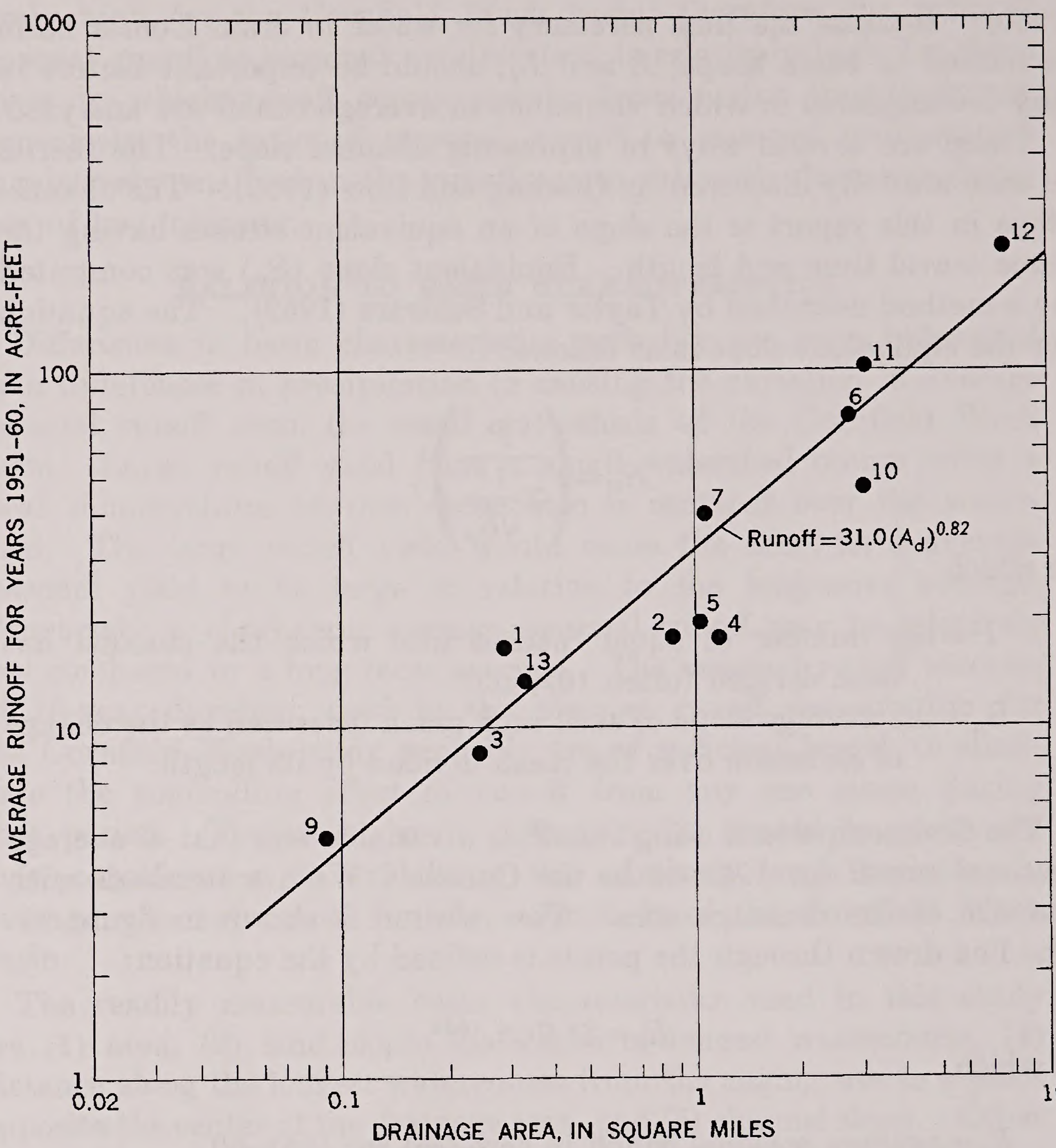

FIGURE 11.—Relation of average runoff for 1951-60 to size of drainage basin. Numbers indicate watersheds in which measurements were made.

difference is that the channels are bare, raw, and narrow. Grass does not grow in the channels, and there are no sediment deposits throughout their length; therefore, they are unlike the average channel and the conveyance losses undoubtedly are small.

The channels of watershed 4 are broad, contain grass, and therefore are the opposite of those of watershed 7. Consequently, the computed runoff for an average condition is greater than measured at watershed 4.

The computed runoff of watershed 1 is larger than the measured runoff; however, the reason for the difference cannot be determined from the available data.

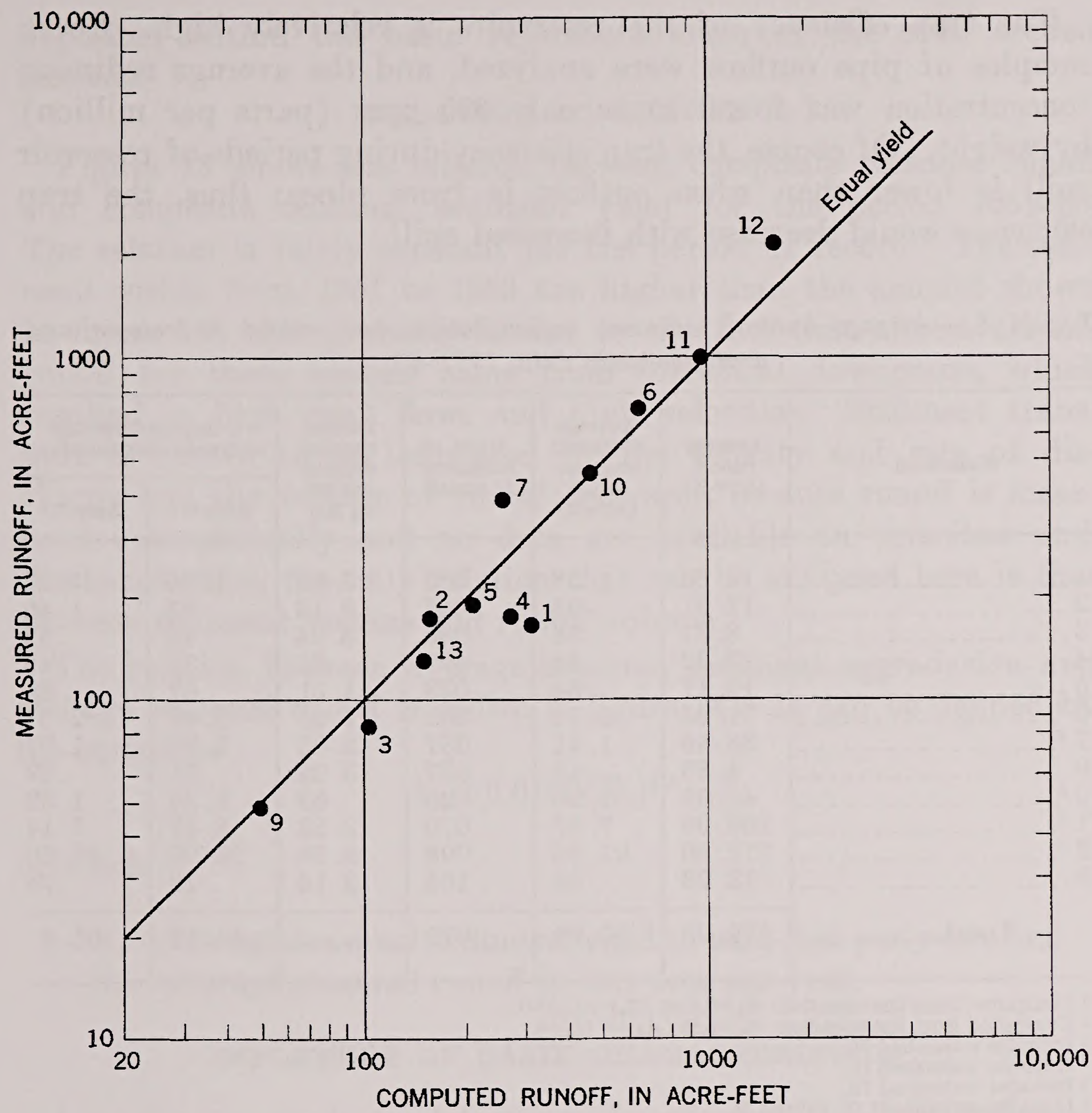

FIGURE 12.—Comparison of computed runoff to measured runoff for 1951–60. Numbers indicate watersheds in which measurements were made.

SEDIMENTATION

TABULATION OF DATA

The annual runoff and the annual accretion of sediment in each of the reservoirs are summarized in table 5. The average sediment deposition at each of the reservoirs in the 10-year period, 1951–60, and the ratio of sediment volume to runoff volume are given in table 8.

Shrinkage and compaction of sediment from one season to another was a major source of possible error in determining small amounts of seasonal sediment accumulation. The actual sediment yields for years when sediment accumulation was low in comparison to the sediment accumulation for the preceding year were especially difficult to determine.

The trap efficiency of the reservoirs is relatively high. Seven samples of pipe outflow were analyzed, and the average sediment concentration was found to be only 395 ppm (parts per million) by weight. Of course, the trap efficiency during periods of reservoir spill is lower than when outflow is from pipes; thus, the trap efficiency would decrease with increased spill.

TABLE 8.—*Average annual sediment accumulation and related hydrologic and drainage-basin data, 1951–60*

Watershed	Average runoff (acre-ft)	Average sediment accumulation (acre-ft)	Ratio of sediment to runoff	Incised channel density (mi per sq mi)	Computed average sediment accumulation	
					Acre-ft [1]	Acre-ft [2]
1	16. 60	1. 38	0. 083	5. 63	1. 56	1. 37
2	17. 31	. 98	. 057	2. 13	. 83	1. 46
3	8. 31	. 38	. 046	3. 04	. 42	. 52
4	17. 32	. 48	. 026	. 61	. 34	. 42
5	19. 17	. 64	. 033	1. 31	. 67	. 85
6 [3]	71. 24	4. 14	. 058	1. 21	3. 47	2. 81
7 [4]	38. 46	1. 41	. 037	2. 05	2. 38	1. 77
9	4. 85	. 18	. 037	3. 22	. 21	. 02
10 [5]	47. 62	1. 20	. 025	. 62	1. 35	1. 32
11 [6]	100. 06	7. 87	. 079	2. 26	8. 47	7. 14
12 [7]	217. 86	21. 38	. 098	2. 30	23. 69	17. 50
13	13. 23	. 95	. 105	3. 14	. 78	. 76
Total	572. 03	40. 99	. 072	--------	44. 17	35. 9

[1] Computed from the equation: $S_a=0.0189\,(R_a)^{1.3}\,(I_d)^{0.71}$.
[2] Computed from the equation: $S_a=6.52\,(A_d)^{1.19}\,(I_d)^{1.3}$.
[3] Includes watershed 17.
[4] Includes watershed 16.
[5] Includes watershed 10.
[6] Includes watersheds 18, 19, and 21.
[7] Includes watershed 20.

Although the records of annual sediment impounded during years of low sediment yield are recognized as being somewhat unreliable, the accuracy of the data on sediment accumulation in each reservoir for the total period of record is fair to good. Therefore, instead of using annual sediment yields for each watershed, composite annual sediment yields and average sediment yields are used in the studies that follow.

It is important to differentiate between the quantity of sediment deposited in a reservoir and the total amount eroded from the watershed. The sediment deposited in a reservoir plus the amount lost through outflow represent the total sediment transported from a basin. The sediment deposited in a reservoir plus the amount lost through outflow and the amount deposited within the basin represent the total eroded amount. Undoubtedly, in many basins where discontinuous channels are prevalent, the amount of sediment

deposited within the basin represents much of the total eroded amount.

RELATION TO RUNOFF

Figure 13 shows the relation between composite seasonal runoff and composite seasonal sediment yield for the period 1951–60. The relation is fairly constant for the period of record. The sediment yields from 1951 to 1953 are higher than the amount shown in figure 13; this probably is due to the fact that almost all the runoff for these seasons came from torrential downpours, which resulted in high peak flows and high velocities. Sediment transport is known to be influenced by the velocity and rate of discharge and the volume of runoff; however, because runoff is measured volumetrically and no data are available on velocities and discharge rates, the only relation that can be analyzed here is that between sediment volume and runoff volume.

The relation between average seasonal sediment aggradation and average seasonal runoff is shown in figure 14. It can be defined by the equation:

$$S_a=0.0189(R_a)^{1.3},$$

in which

S_a=average seasonal sediment yield in acre-feet per year; and
R_a=average seasonal runoff in acre-feet per year.

INFLUENCE OF BASIN CHARACTERISTICS

A study was made to determine the effects of various drainage-basin characteristics on the relation between average seasonal sediment yield and average seasonal runoff for the watersheds in Cornfield Wash. The drainage-basin characteristics used in the study were L, S_{st}, L_s, A_d, and density of incised channels (I_d). An incised channel is one in which the flow of water has cut sharply into the earth and is characterized by steep-sided banks regardless of the size of channel. Incised-channel density is the total length of the incised channels of a watershed divided by the size of the watershed.

Using multiple-correlation analysis, average sediment aggradation can be defined by the equation:

$$S_a=0.0189(R_a)^{1.3}(I_d)^{0.71}.$$

The relation between measured and computed sediment accumulation is shown in table 8.

For most watersheds in which sediment data are not available, runoff data also are lacking. Therefore, a method for estimating

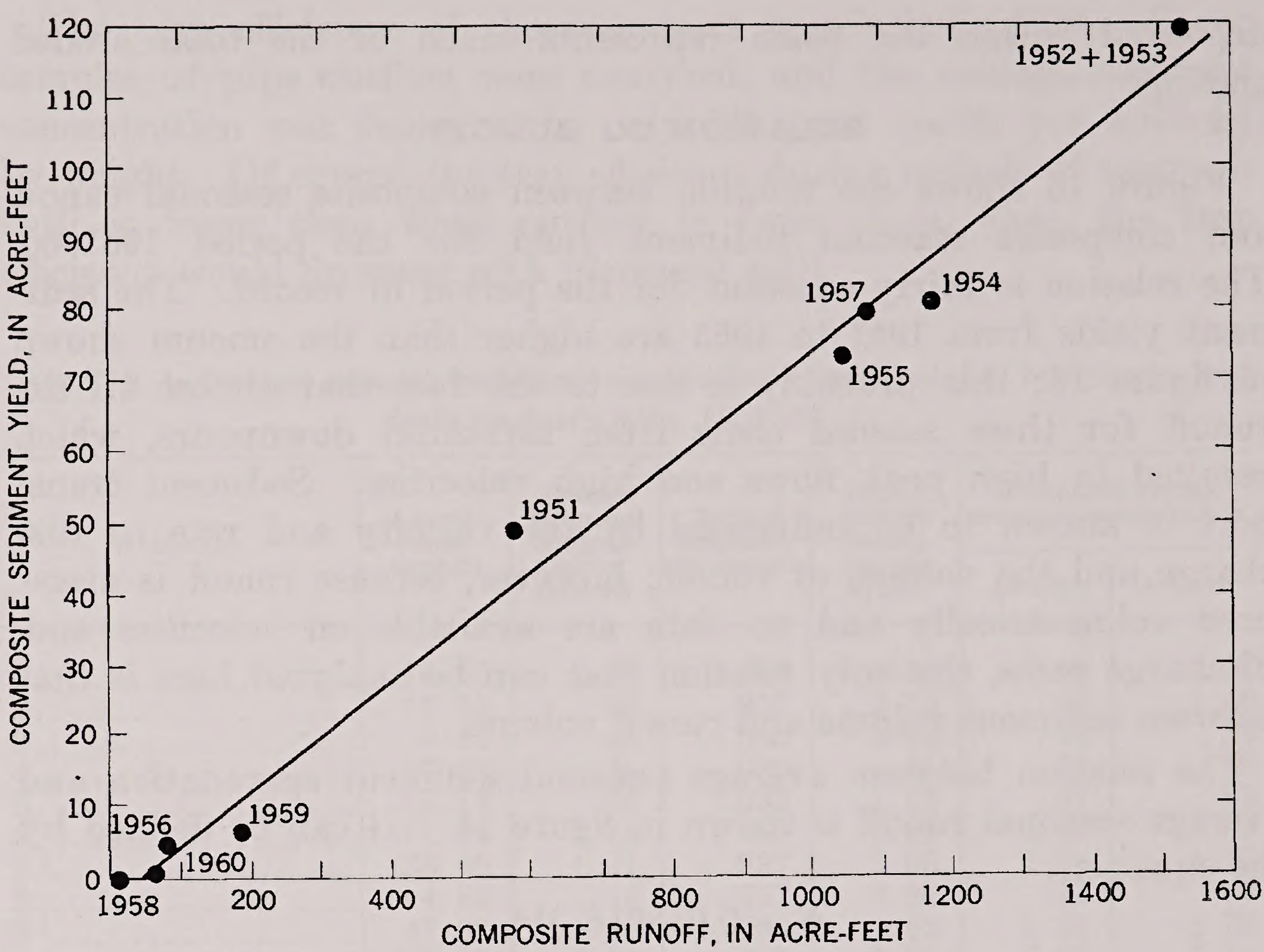

FIGURE 13.—Relation between composite seasonal runoff and composite seasonal sediment, 1951–60.

average sediment yield based on drainage-basin characteristics is desired. The following equations

$$R_a = 10{,}168(A_d)^{0.826}(S_L)^{2.235}$$
$$S_a = 0.0119(R_a)^{1.3}(I_d)^{0.71}$$

suggest that the average annual sediment yields are related to the variables I_d, A_d, and S_L. Using multiple-correlation methods and A_d, I_d, and S_L as independent variables, the average annual sediment yield is best defined by the equation:

$$S_a = 6.52(A_d)^{1.19}(I_d)^{1.3}.$$

The relation of measured sediment to sediment computed from the equation given above is shown in table 8.

Obviously, the two equations for S_a are applicable only for the period 1951–60 in the Cornfield Wash basin. How applicable the equations are to other drainage basins and for other periods of time cannot be determined by the available data.

It would have been desirable to analyze the effects of soil type, vegetation cover, and hydrologic variables, such as rainfall type and

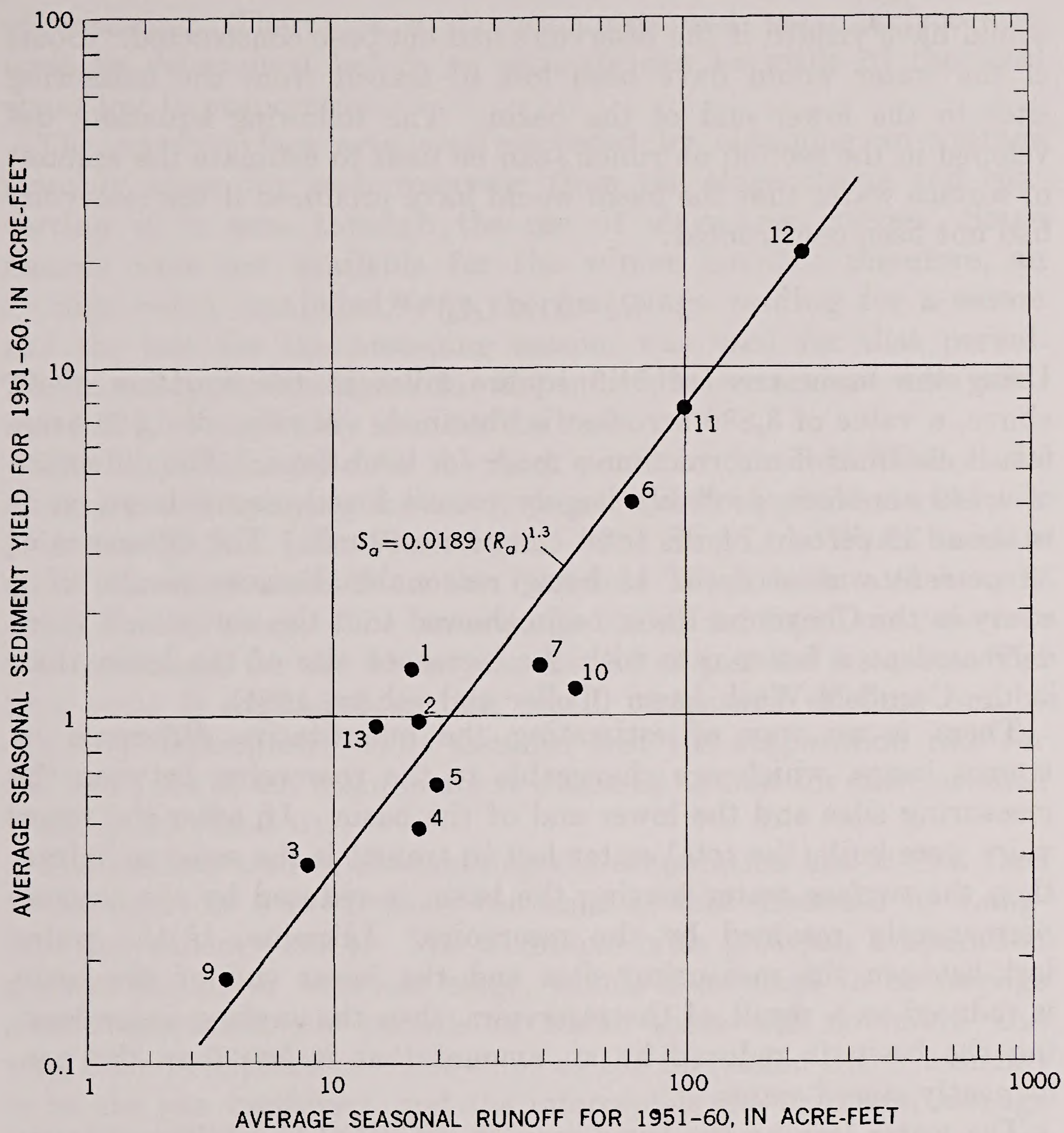

FIGURE 14.—Relation between average seasonal sediment yield and average seasonal runoff (1951–60) for the watersheds in the basin. Numbers indicate watersheds in which measurements were made.

intensity, moisture condition prior to storms, and rate and velocity of discharge on sediment yield, during this study. However, data were not available. Perhaps in time, adequate data for small watersheds will be available, and the effects of these variables on sediment yield can be determined.

EFFECTS OF LAND TREATMENT

RESERVOIRS

TRANSIT LOSSES

The total composite runoff of 5,720 acre-feet for the 10 years of study does not represent the amount of surface water that the basin

would have yielded if the reservoirs had not been constructed. Some of the water would have been lost in transit from the measuring sites to the lower end of the basin. The following equation, developed in the section on runoff, can be used to estimate the amount of surface water that the basin would have produced if the reservoirs had not been constructed:

$$R_a = 31.0\ (A_d)^{0.82}.$$

Using the basin area of 21.3 square miles in the equation given above, a value of 3,880 acre-feet is obtained. A value of 3,620 acre-feet is obtained if a correction is made for land slope. The difference of 1,840 acre-feet, probably largely transit losses, seems large, as it is about 32 percent of the total composite runoff. The difference of 32 percent was accepted as being reasonable because results of a study in the Cheyenne River basin showed that the unit runoff there decreased at a faster rate with the increased size of the basin than in the Cornfield Wash basin (Culler and others, 1961).

There is no way of estimating the quantitative difference in transit losses, which are chargeable to the reservoirs, between the measuring sites and the lower end of the basin. If, after the reservoirs were built, the total water lost in transit is the same as before, then the surface water leaving the basin is reduced by the amount permanently retained by the reservoirs. Likewise, if the water lost between the measuring sites and the lower end of the basin is reduced as a result of the reservoirs, then the surface water leaving the basin is reduced by an amount that is less than the permanently stored water.

The water leaving the basin may be subjected to additional losses by the change in the runoff regime caused by the reservoirs. With the data available, this possible effect on downstream water cannot be estimated.

EVAPORATION LOSSES

The water retained in the reservoirs is subjected to losses by evaporation, seepage, and, to a minor extent, by livestock use. Evaporation loss and water consumed by livestock are not recoverable, whereas seepage loss may be partly recovered. The nonrecoverable loss to permanent storage can be considered a direct charge against the reservoir effects only if the nonrecoverable quantitative transit loss between the storage site and the point of interest downstream is the same or greater after the reservoir was constructed as before.

The amount of water lost to evaporation is a function of the water-surface area exposed and the evaporation rate at the time

of exposure. Therefore, evaporation rate and water-surface area must be determined before an estimate can be made of the total water lost to evaporation.

The water-surface area was computed by obtaining an average monthly stage for each reservoir from the stage charts and converting it to area through the use of stage-area curves. Stage records were not available for the winter months; therefore, an average value, computed from the first stage reading for a season and the last for the preceding season, was used for that period. The monthly surface areas for the individual reservoirs were combined to give a monthly sum for the basin.

The evaporation rate for the stock ponds in Cornfield Wash basin was estimated by using the water-stage records obtained at reservoir 3 in nearby San Luis Wash basin. The San Luis Wash basin is about the same altitude as the Cornfield Wash basin and is only about 8 miles away. The water-stage record for San Luis reservoir 3 is continuous for the whole year instead of just for a season. The time scale is expanded so that small increments of time can be correctly determined. It is assumed that the evaporation rate for the San Luis Wash basin is about the same as that for the Cornfield Wash basin (table 9).

The method used in determining the evaporation loss at San Luis Wash reservoir 3 is virtually the same as that described by Langbein and others (1951). The technique is to plot pan evaporation against change in reservoir stage, which is assumed to be seepage plus evaporation, for periods in which there was no inflow and very little precipitation. The slope of the regression line is assumed to be the pan coefficient, and the intercept is the minimum seepage loss. The pan evaporation at Jemez Canyon Dam (pl. 1) was used in the study.

The monthly evaporation loss in the Cornfield Wash basin was determined by applying the monthly evaporation rate shown in

TABLE 9.—*Seasonal stock-pond evaporation, San Luis Wash reservoir 3*

Month	Median evaporation		Month	Median evaporation	
	Inches per day	Inches		Inches per day	Inches
January	0.024	0.74	August	0.223	6.91
February	.022	.62	September	.192	5.76
March	.076	2.36	October	.119	3.69
April	.152	4.56	November	.076	2.28
May	.226	7.01	December	.046	1.43
June	.272	8.16			
July	.246	7.63	Total	.140	51.15

table 9 to the composite area of water of all the reservoirs. The annual evaporation loss is the sum of the monthly values (table 10). Some of the seepage loss more correctly may be classified as evaporation loss because the technique used in computing evaporation did not make allowances for the loss from surfaces wetted by seepage. Even so, it is believed that the computed evaporation loss is reasonable. The 591 acre-feet of evaporation loss (table 10) for the 10 years of record is 43 percent of the permanently stored runoff and about 10 percent of the total composite runoff of the basin.

SEEPAGE LOSSES

Seepage can be divided into two types—water that percolates downward to the water table, and water that, for the most part, percolates through or under the dams and probably never sinks more than a few feet below the surface. No attempt was made to separate or evaluate the two types of seepage, but the relative amounts probably would be different for each reservoir.

TABLE 10.—*Annual evaporation and seepage from the reservoirs in Cornfield Wash basin, 1951–61*

[Measurements in acre-feet]

Date	Reservoir content	Change in reservoir content	Composite runoff permanently retained	Evaporation and seepage	Computed evaporation	Seepage
June 1						
1951	0	------	------	------	------	------
1952	16	+16	195	179	152	27
1953	8	−8	282	280	66	224
1954	10	+2	222	220	78	142
1955	3	−7	227	234	106	128
1956	0	−3	130	133	56	77
1957	0	0	28	28	16	12
1958	8	+8	173	165	79	86
1959	0	−8	0	8	7	1
1960	3	+3	62	59	28	31
1961	0	−3	54	57	3	54
Total	------	------	1, 373	1, 373	591	782

The water that becomes a part of the ground-water supply may remain in the recharge aquifer more or less permanently, or it may return to surface flow through springs or seeps. There is only one known spring in or near the Cornfield Wash basin; therefore, the return flow by springs probably is minor. The spring, which is in an arroyo just downstream from reservoir 4, has produced a small amount of flow during most of the period of record. This flow disappears by evaporation and seepage into the streambed within a mile.

Seeps from the banks are more difficult to detect than springs, although the total amount of water from them is probably greater. Seep water commonly is evaporated about as fast as it is discharged from the soil, and in warm dry weather it may not be noticed. In the winter, however, seeps are sometimes noticeable as icy sheaths or "cascades" where the seep water freezes on the surface before it can evaporate. Thus, the part of the water from return seepage flow is either consumed by transpiration or lost to direct evaporation.

FLOOD CONTROL

Storm flows from 1956 through 1960 were reduced sufficiently by the reservoirs that no damage was done to the Indian farmland below the basin. The flood of August 5–6, 1957, was the only one that would have caused any damage even if the reservoirs had not been constructed. The storm produced about 450 acre-feet of runoff, which had a peak rate of flow that may have damaged some of the farmland below reservoirs 11 and 12. Unlike the floods from 1951 through 1955 (Kennon and Peterson, 1960), the runoff from 1956 through 1960 came from rainfall of relatively low intensity. Therefore, the peak flow, even if uncontrolled, probably would not have been large, and the damage to downstream farmland would have been small.

WATER SUPPLY

The reservoirs supplied domestic, stock, and irrigation water for the Indian settlers from 1951 through 1955 (Kennon and Peterson, 1960, p. 99). From 1956 through 1960, however, the reservoirs did not contain enough water for these uses, owing to the long periods of no runoff and reduced reservoir storage capacity resulting from sedimentation. From September 1958 until July 1959 there was no water in any of the reservoirs. There were long periods of time in 1956, 1958, 1959, and 1960 when the only water available was at reservoir 2. Large amounts of water were available for irrigation during the "wet" year of 1957 but were not used because of the large amount of rainfall during the growing season. The reservoirs contained practically no water during the low-runoff years of 1956, 1958, 1959, and 1960. Some of the water retained in the freshly deposited sediments of the reservoirs probably could have been utilized during dry periods. Shallow wells drilled in the sediments of some of the reservoirs may have produced sufficient water for domestic and stock uses.

SEDIMENTATION AND EROSION

As a result of the reservoirs, 410 acre-feet of sediment was impounded from 1951 through 1960 in the Cornfield Wash basin.

About 390 acre-feet was impounded in the reservoirs; the remainder was deposited in the channels in which backwater from the reservoirs had influenced sediment deposition. The 410 acre-feet of sediment represents annual deposition of about 1.9 acre-feet per square mile for the 21.3 square miles of drainage area.

The aggregate storage capacity at the spillway level of reservoirs 1–17 was reduced from 791.3 acre-feet to 408.6 acre-feet in the 10-year study period, which is a 48 percent reduction in storage capacity. The aggregate storage capacity of reservoirs 18–21, which were built to conserve the storage capacity of the original 15 reservoirs, was reduced from 54.1 acre-feet to 46.0 acre-feet from 1956 through 1960. The aggregate storage capacity of all the reservoirs in the basin is now (1960) 52.4 percent of the original capacity.

A good method of estimating the amount of sediment that would have been transported from the basin if the reservoirs had not been constructed has not been found. The reservoirs were effective in decreasing the rate of flow in the main channels of the Cornfield Wash basin. Therefore, because sediment yield per unit of runoff is known to decrease as the velocity and rate of flow decreases, the amount of sediment that would have moved from the basin if the reservoirs had not been constructed may have been greater than the 410 acre-feet impounded.

It is not known to what extent the reduction in sediment that leaves the Cornfield Wash basin affects the downstream sediment yields. On the one hand, the relatively sediment-free water that leaves the basin will again acquire a sediment load if erodable materials are available, and on the other hand, the uncontrolled peak flows may have greater eroding power. The magnitude of the new sediment load could not be determined from available data.

GULLY CONTROL

The reservoirs that were built to stop the advance of abrupt "headcuts" have been successful in some instances and only partly successful in others. The success of a reservoir in stopping the advance of an abrupt "headcut" depends mainly on the amount of water that spilled.

The reservoirs, once they become filled or almost filled with sediment, effectively increase the declivity of the route by which the spill water must travel (fig. 15). The spill water is restricted to the width of the emergency spillway. A very rapid increase in velocity of the relatively sediment-free spill water, which results in increased sediment-carrying capacity, is the direct effect of the steep slopes and restricted spillway section. The end result is the rapid erosion of the spillway and the advance of the headcut that the

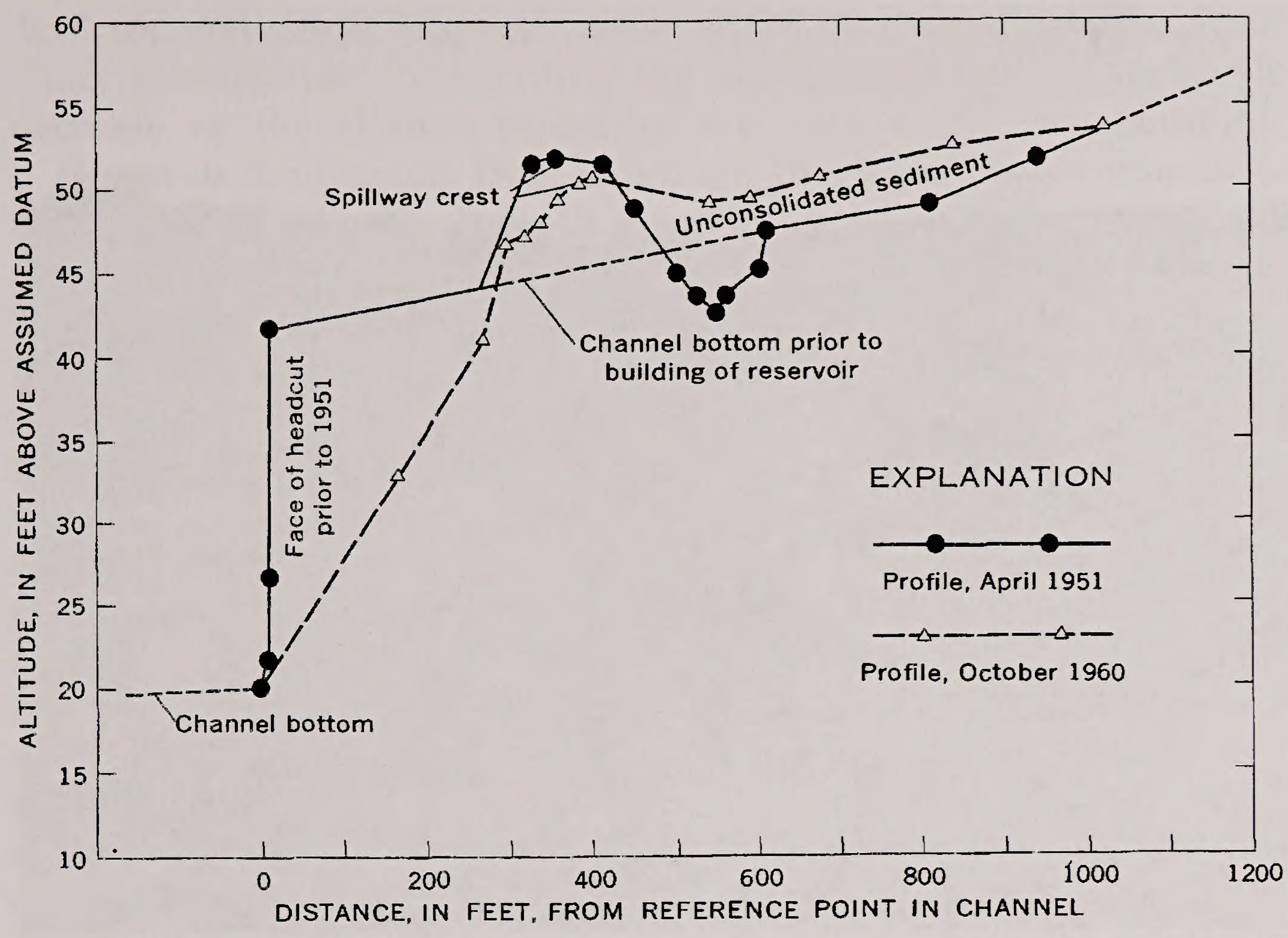

FIGURE 15.—Profile of reservoir filling and channel erosion, at reservoir 5.

structure was built to protect. Of course, spillways cut in rock remain secure, but those cut in thin shale and alluvium erode rapidly.

The spillways of the reservoirs built in V-shaped valleys are more vulnerable to rapid erosion than those of reservoirs in broad valleys. The dams in the V-shaped valleys must be relatively high to acquire enough storage to contain the floodflows. The water that leaves the reservoirs through the spillways has no place to go but directly back into the channel. Channels draining small watersheds are usually of the V-shaped variety. Figures 15 and 16 illustrate the progress of erosion and sedimentation of a reservoir in a V-shaped valley. There is no doubt as to what will inevitably happen to the spillway of thin shale and to the unconsolidated sediment in the reservoir. Raising the dam and spillway would only serve to increase the slope of the watercourse, and when the reservoir is again filled with sediment, the spillway will start to erode. The only way to stop the advance of the headcut is to stabilize the spillway section, a situation only slightly less complicated than stabilizing the original channel. Reservoirs 3 and 13 have reached a stage of sedimentation and spillway erosion similar to that of reservoir 5.

Fortunately, not all the reservoirs in the V-shaped valleys are as full of sediment as reservoir 5. The storage capacities of reservoirs

A. Looking downstream, September 1951. Photograph by R. C. Culler.

B. Looking upstream, October 1960. Photograph by F. A. Branson.

FIGURE 16.—SPILLWAY EROSION AT RESERVOIR 5.

1, 4, 9, and 15–21 are still sufficient to contain most floodflows. Their effectiveness in retarding the advancement of headcuts will decrease as the storage capacities are reduced by sedimentation.

Reservoir 6, upstream from an arroyo 15–20 feet deep, seems to be performing effectively—in both trapping sediment and reducing the advance of the downstream arroyo—although it is full of sediment. The dam is across a gently sloping valley about 500 feet wide; therefore, it was not necessary to construct a high dam in order to provide enough storage to retain the floodflows. Sediment has filled the reservoir to spillway level and in doing so has formed a relatively wide shallow valley upstream. The velocity of the floodflows is reduced as the water spreads across the valley, which results in the progression of sedimentation upstream. The spillflow and the outflow from reservoir 7 are routed through nine spreader areas (pl. 1) before entering the deep arroyo at a point about 2 miles downstream. The rate of flow of the water entering the channel is small. A small rill has formed in the spillway of reservoir 6 that probably will extend itself through the fill of the reservoir if the spillway is not stabilized. Unlike the reservoirs in the V-shaped valleys, the stabilization of the spillway seems worthwhile, as both the relatively large valley above the reservoir and the spreader system below are being jeopardized.

The progress of deposition in reservoirs 7, 10, 11, and 12 has not reached the stage of reservoir 6, but eventually it will. The spillways of reservoirs 11 and 12 are cut from rock and are stable. The spillways of reservoirs 7 and 10 will eventually have to be stabilized to insure continuous successful operation.

VEGETATION

Annual weeds, of which Russian-thistle (*Salsola kali*) and sunflowers (*Helianthus annuus*) are the most numerous, are currently (1960) the prevailing vegetation in the induced sediment deposits in the reservoirs. A sparse stand of alkali sacaton (*Sporobolus airoides*) is present with annual weeds along the outer edges of the reservoirs where the sediment accumulation is relatively minor. There is a relatively dense growth of saltcedar (*Tamarix pentandra*) in reservoir 6.

WIRE SEDIMENT BARRIERS

The wire sediment barriers built across the channels above reservoirs 6, 7, 11, and 12 were not as successful in inducing aggradation as expected (fig. 8). Only minor sediment aggradation, determined from annual surveys, could be accredited to the wire barriers. The sediment barriers probably will be the most effective during runoff from major thunderstorms. Unfortunately, since the barriers were

constructed in 1956, the runoff has been mainly from frontal storms of relatively low rainfall intensities. Therefore, conclusions on the effects of the sediment barriers cannot be made until more data are obtained.

RANGE PITTING

RUNOFF

Two basic methods are available for evaluating the effects of pitting on water yields: (1) a comparison of treated and untreated replicated watersheds in the same climatic zone, and (2) an evaluation of changes in the relation between precipitation and runoff that occurs within a watershed after the treatment is applied.

As described under the discussion on runoff, the available data are not adequate for the establishment of a good relation between rainfall and runoff; therefore, method (2) could not be used. It would take an estimated 15–20 years of good data to establish a runoff-precipitation relation for the watersheds of the Cornfield Wash basin that would adequately define the probable minor change in runoff caused by pitting.

The runoff data necessary to use the first method are almost as inadequate as the precipitation data for the second method. The usual approach in using the first method is to calibrate the runoff from two or more adjacent similar watersheds before treatment so that changes in runoff due to treatment can be detected. Unfortunately, pitting in the Cornfield Wash basin was applied before data for the establishment of good runoff relations between adjacent watersheds were collected; therefore, there was no way of knowing how well the natural runoff from a treated watershed could be estimated from the runoff from an adjacent untreated watershed.

Comparative studies of runoff from treated and untreated watersheds were made, although the data were recognized as being inadequate. No effects of pitting on runoff were found. Whether this was because there were no effects or because the data collected were insufficient to define the change could not be determined.

SEDIMENT

As the effects of pitting on runoff could not be determined, the effects of pitting on sediment yield also could not be defined.

SOIL MOISTURE

Comparative sets of soil samples taken in May 1958 showed a greater moisture content for samples taken directly from pits than for those taken between pits. Sets of samples were taken at two locations—one site was devoid of vegetation, and the other had a grass cover. The moisture content in the pits of the grass-covered

site was 12.5 percent, whereas the moisture content between pits at the same site was 11.8 percent. The moisture content in the pits of the site that was devoid of vegetation was 11.4 percent, whereas the moisture content between pits at the same site was 10.5 percent. Practically all the difference in moisture content between samples taken from pits as compared to those taken between pits occurred in the upper 24 inches of the 42-inch sampling depth. Because there was no runoff from either pitted or unpitted watersheds for 6 months prior to May 1958, the increased moisture may have been the result of snow trapped in the pits.

Field measurements in August 1959, following a period of runoff, showed that, except for deep sandy soils, the moisture penetrated to depths slightly greater in pitted watersheds than in the unpitted watersheds. Pitting in the sandy soils did not increase the infiltration rate.

A study conducted in 1960 to determine whether pitting caused a seasonal increase in soil moisture showed that the soil-moisture content increased in the pitted areas slightly more than in the unpitted areas. Comparative sets of soil samples were taken at both sites at the beginning of the runoff season and again at the end of the season. The average increase in soil moisture in the pitted watershed was 5.2 percent, whereas the average increase in soil moisture in the unpitted was 4.4 percent.

The reconnaissance-type studies indicate that there was an increase in soil moisture as a result of range pitting. However, intensified studies will be necessary before conclusive statements can be made on the magnitude of the increase and on the duration of the useful life of the treatment practice in increasing soil moisture.

VEGETATION

In 1958 two pairs of contiguous watersheds—above reservoirs 7, 9, 10, and 16—similar in soil and vegetation types were selected for measurements of the effects of pitting on vegetation yields. The two untreated watersheds contained 330 and 350 acres, and the two treated watersheds contained 60 and 1,290 acres.

Portable exclosures (wire cages), 6 feet long, 3 feet wide, and 23 inches high, were used to exclude grazing animals from plots for measuring seasonal vegetation yields. Each of the two pairs of watersheds was equipped with 20 exclosures (fig. 17). The 40 exclosures were placed at random in the four watersheds by means of grids and tables of random numbers. Sampling points were located in the field by the use of an alidade. Vandals moved or destroyed some of the portable exclosures each year. In 1958, 1959, and 1960 it was possible to obtain samples from 38, 36, and 35 plots,

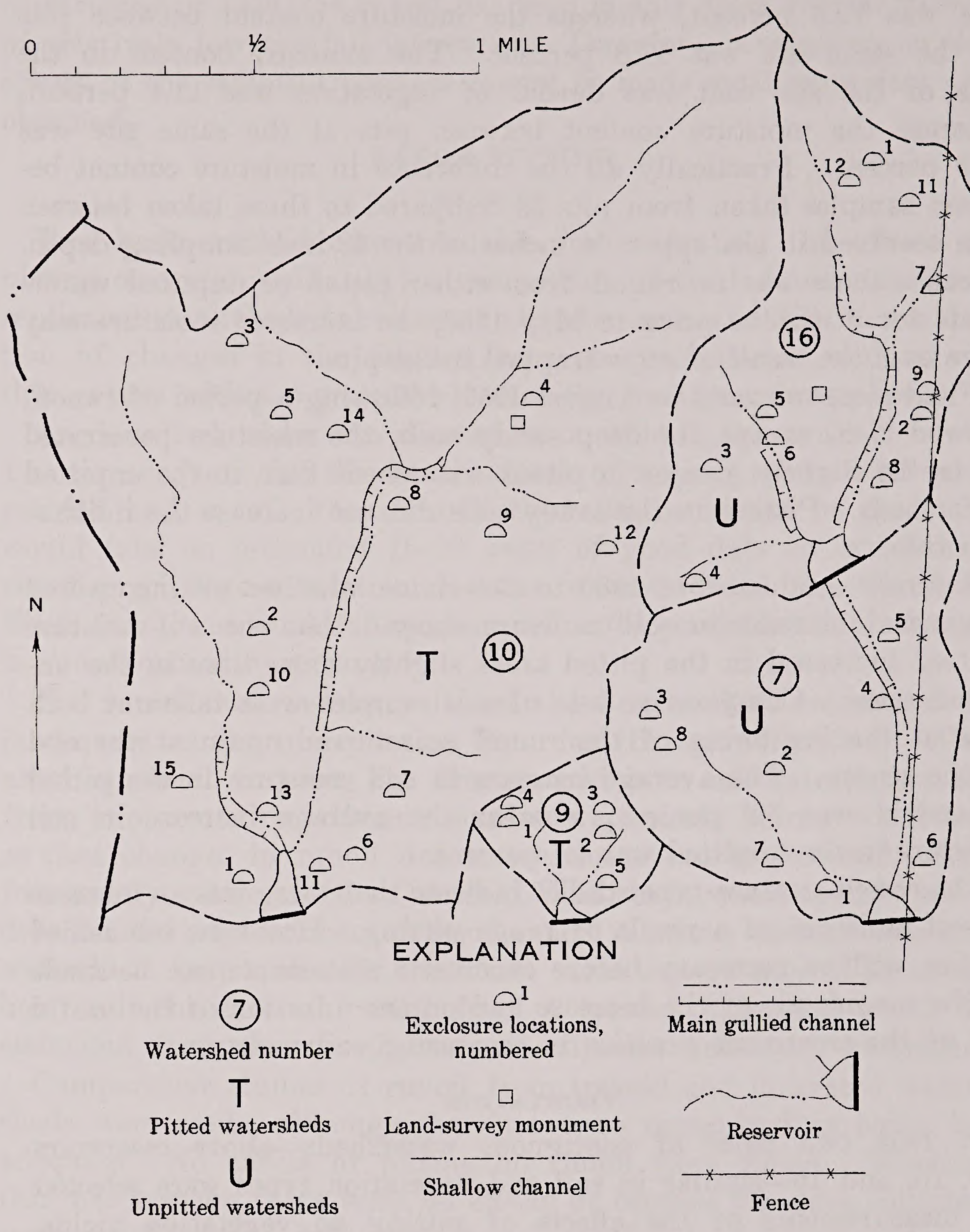

FIGURE 17.—Location of portable exclosures in two pitted and two unpitted watersheds.

respectively. Determinations of yield were made by hand clipping the vegetation in late fall when nearly all the growth by the herbaceous species had been completed.

Grass yields in the pitted watersheds exceeded those from the untreated watersheds by about 70 percent (table 11). However, the high yields of forbs, especially Russian-thistle, in the untreated watersheds caused the total yields from the treated and untreated watersheds to be nearly the same. Reconnaissance studies showed

TABLE 11.—*Yields, in pounds per acre, for two pitted and two untreated watersheds in the Cornfield Wash basin*

[Yields are from 38, 36, and 35 plots for 1958, 1959, and 1960, respectively]

Basin	Year	Grasses									Forbs					Shrubs				Mulch	Total vegetation
		Arizona three-awn (*Aristida arizonica*)	Blue grama (*Bouteloua gracilis*)	Galleta (*Hilaria jamesii*)	Ring muhly (*Muhlenbergia torreyi*)	Indian ricegrass (*Oryzopsis hymenoides*)	Alkali sacaton (*Sporobolus airoides*)	Sand drop-seed (*Sporobolus cryptandrus*)	Other grasses	Total grasses	Russian-thistle (*Salsola kali*)	Wooly Indian-wheat (*Plantago purshii*)	Lambsquarters (*Chenopodium album*)	Other forbs	Total forbs	Big sagebrush (*Artemisia tridentata*)	Winterfat (*Eurotia lanata*)	Other shrubs	Total shrubs		
Pitted basin																					
9	1958	9	25	61	31	36		6		168	157			3	160	6			6		334
	1959	7	26	74	58			15		180	244		1		245					107	425
	1960	2	25	101	28	7		27		190	174				174			10	10	410	374
10	1958		16	192	128		21	31		388	450	T		3	453						841
	1959		21	329	22		14		11	397	92			3	95			9	9	309	501
	1960		30	165		1	27	147	1	371	153			4	157	10			10	863	538
Total										1, 694					1, 284						3, 013
Average										282					214						502
Untreated basin																					
7	1958	17	23	134	22		7			203	236			18	254						457
	1959	4	44	74	26		1	2		151	169		1	1	171					74	322
	1960	1	35	89	2					127	177			3	180					223	307
16	1958	1	22	63	6		1	T		93	678			1	679						772
	1959	13	39	127			39	2		220	236		1	1	238					272	458
	1960	12	8	153			25			198	442			59	501		14	28	42	395	741
Total										992					2, 023						3, 057
Average										165					337						510

the soil moisture to be greater and moisture penetration to be deeper in the pitted than in untreated watersheds (p. 67). The deeper penetration and greater quantities of soil moisture present may have caused perennial grass production to be greater in the pitted watersheds, but the similar total yields from treated and untreated watersheds would make the assumption that pitting caused the increase in grass production questionable. Also, because vegetation yields prior to treatment were not available, any statements pertaining to the effects of pitting would be inconclusive.

COMPARISON OF DATA FROM CORNFIELD WASH BASIN WITH DATA FROM NEARBY BASINS

An investigation to determine if the Cornfield Wash basin is representative of the Rio Puerco and other nearby basins was made by comparing the data from the Cornfield Wash basin with that from other nearby watersheds. The hydrologic and readily measurable physical basin-characteristics data are compared and discussed in the following sections.

PRECIPITATION

The low-intensity rainfall after 1956 may have been a local phenomenon that occurred only in the Cornfield Wash basin. In order to investigate this possibility, preliminary studies were made of the rainfall intensities recorded at nearby U.S. Weather Bureau stations. Although the investigations were not exhaustive, they indicated that the low-intensity rainfall recorded at Cornfield Wash after 1956 was prevalent at the nearby U.S. Weather Bureau gages.

Further comparison of the precipitation in the Cornfield Wash basin with that of nearby stations was made by plotting the average seasonal precipitation from 1951 through 1960 at each station against respective altitudes. The relation indicates that the seasonal averages increase by 0.10 inch per 100 feet of increased altitude (fig. 18). A similar study by Mead (1950) in western New Mexico and eastern Arizona indicates that annual precipitation increases on the average of 0.15 inch per 100 feet increased altitude. Therefore, the two relations are in general agreement, and the average seasonal precipitation shown in figure 18 is about 65 percent of the average annual amounts.

The plot of average seasonal precipitation (fig. 18) against altitude does not give a true picture for the U.S. Weather Bureau stations at Wolf Canyon, Jemez Springs, and Bandelier National Monument. These stations are in relatively narrow valleys that are paralled by high mountains. Therefore, the amounts of precipitation are not indicative of the altitude of the gages; instead, they reflect the altitude of the nearby mountains.

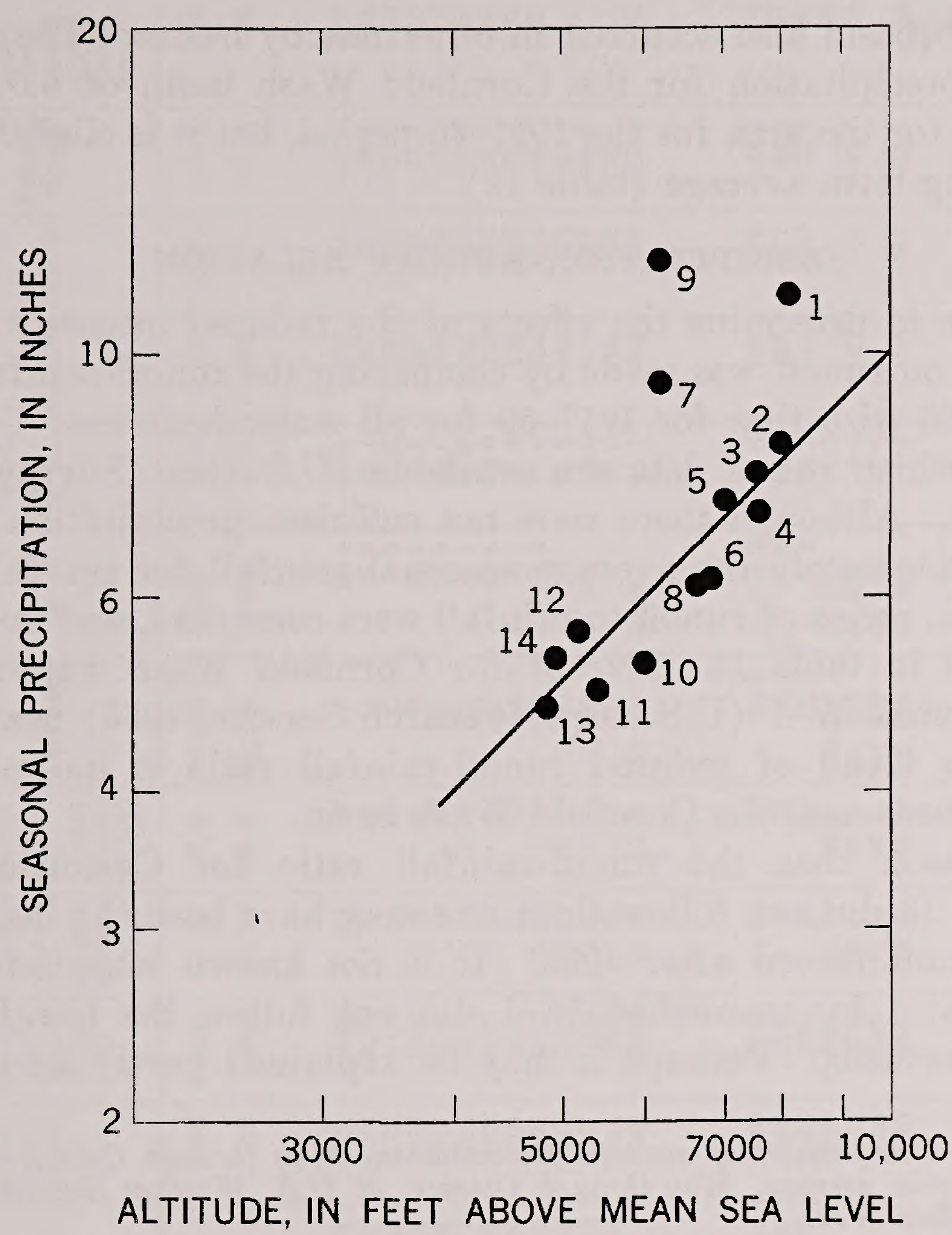

FIGURE 18.—Relation of average seasonal precipitation (May through October) to altitude for stations near the Cornfield Wash basin, 1951–60. Reference numbers from table 12.

Based on the precipitation studies, it may be concluded that storm rainfall near Cornfield Wash varies considerably from watershed to watershed, but the average seasonal rainfall for several years of record is nearly equal over relatively large areas if there are no outstanding topographic differences. In general, variability of precipitation decreases with the increase in the time unit being considered, and the variability of average precipitation over a basin or other area is less than at one point (Linsley and others, 1949). Seasonal precipitation varies with altitude (fig. 18), but even so, in nonmountainous basins the difference in seasonal precipitation as a result of differences in altitude is small for relatively large areas. Further conclusions are that the precipitation pattern in the Cornfield Wash basin is similar to that of other nearby basins, and the change in precipitation pattern that occurred in the Corn-

field Wash basin also occurred in other nearby basins. The average seasonal precipitation for the Cornfield Wash basin of 6.07 inches is normal for the area for the 1951–60 period, but it is slightly lower than a long-term average (table 12).

PRECIPITATION-RUNOFF RELATION

A study to determine the effects of the reduced intensity of precipitation on runoff was made by comparing the runoff-rainfall ratio for 1951–56 with that for 1957–59 for all watersheds near Cornfield Wash in which runoff data are available (U.S. Geol. Survey, issued annually). Although there were not sufficient precipitation records to define accurately the average seasonal rainfall for several of the watersheds, ratios of runoff to rainfall were computed, and the results are shown in table 13. Except for Cornfield Wash watershed 13 and watershed W–I (U.S. Agr. Research Service, 1956) near Albuquerque, a trend of reduced runoff-rainfall ratio is indicated for all watersheds near the Cornfield Wash basin.

The reason that the runoff-rainfall ratio for Cornfield Wash watershed 13 did not follow the trend may have been the inaccuracy of the runoff record after 1956. It is not known why the runoff-rainfall ratio for watershed W–I did not follow the trend of the other watersheds. Perhaps it may be explained partly by the fact

TABLE 12.—*Comparison of average precipitation, May through October 1951–60, and long-term average, May through October, at U.S. Weather Bureau stations near Cornfield Wash*

Station		Altitude (feet above mean sea level)	Seasonal precipitation						
			1951–60			Long-term			
No. on fig. 18	Location		Average (inches)	Standard deviation (inches)	Coefficient of variability (percent)	Year	Average (inches)	Standard deviation (inches)	Coefficient of variability (percent)
1	Wolf Canyon	8,000	11.36	2.43	21.4	1912–60	12.52	3.58	28.6
2	Marquez	7,800	8.27	2.64	31.9	1941–60	8.29	2.58	31.1
3	Regina	7,450	7.68	2.48	32.3	1922–60	9.46	2.86	30.2
4	El Morro	7,414	7.08	2.31	32.6	1938–60	7.44	2.82	37.9
5	Cuba	6,945	7.33	2.64	36.0	1939–60	8.25	2.61	31.6
6	Johnson Ranch	6,700	6.15	2.39	38.9				
7	Jemez Spring	6,100	9.45	4.19	44.3	1910–60	11.75	3.78	32.2
8	Cornfield Wash	6,600	6.08	2.96	48.7				
9	Bandelier Natl. Monument.	6,061	10.24	3.45	33.7	1927–60	10.49	2.72	26.0
10	Laguna	5,840	5.12	2.55	49.8	1927–60	6.55	3.09	47.1
11	Albuquerque	5,310	4.96	1.64	33.1	1892–1960	5.61	2.12	37.8
12	Bernalillo	5,040	5.58	1.36	24.4	1938–60	5.58	2.02	36.3
13	Los Lunas	4,800	4.75	1.70	35.8	[1] 1890–1960	5.64	2.43	43.0
14	Belen	4,800	5.27	2.12	4.02				
Average					35.9				34.7

[1] Record missing for several years.

TABLE 13.—*Drainage-basin and related hydrologic data for Cornfield Wash and nearby watersheds*

No. on figs. 21, 23–25	Gaging station		Drainage-basin data					Runoff 1951–59			Ratio of runoff to rainfall			Percent change of measured runoff to synthetic runoff
	Name	Location	Area (sq mi)	Land slope (ft per ft)	Equivalent slope (ft per ft)	Stream length: Longest (miles)	Stream length: Center of area (miles)	Acre-ft	Acre-ft per yr	Acre-ft per sq mi per yr	1951–56	1957–59	Percent change	
1	Galisteo Creek at Domingo.	Sec. 21, T. 15 N., R. 6 E.	640	0.0550	0.0089	46.9	27.0	80,180	8,910	13.9	0.035	0.030	−14.3	−78
2	Rio Puerco above Chico Arroyo near Guadalupe.	Sec. 21, T. 16 N., R. 3 W.	420	.0720	.0062	45.2	24.9	42,248	5,360	12.8	.058	.005	−91.4	−63
	Cornfield Wash watersheds:													
3	1	Sec. 19, T. 18 N., R. 3 W.	.29	.1204	.0357	.83	.35	166	18.4	63.4	.221	.105	−52.5	−63
4	2	Sec. 9, T. 18 N., R. 3 W.	.87	.0579	.0215	1.23	.49	173	19.2	22.1	.047	.029	−38.3	−62
5	3	Sec. 2, T. 18 N., R. 3 W.	.25	.0768	.0295	.56	.23	83.1	9.2	36.8	.120	.089	−25.8	−59
6	4	Sec. 26, T. 19 N., R. 3 W.	1.18	.0653	.0202	2.16	.91	173	19.2	16.3	.059	.031	−47.4	−65
7	5	Sec. 23, T. 19 N., R. 3 W.	1.04	.0617	.0228	1.69	.93	192	21.3	20.5	.061	.054	−11.5	0
8	6	Sec. 34, T. 19 N., R. 3 W.	[1] 2.77	.0701	.0128	4.23	2.30	712	79.1	28.6	.049	.010	−79.6	−69
9	7	Sec. 33, T. 19 N., R. 3 W.	[2] 1.07	.0663	.0209	2.09	.83	385	42.8	40.0	.128	.086	−32.8	−55
10	9	Sec. 33, T. 19 N., R. 3 W.	.09	.0803	.0357	.28	.19	48.5	5.4	59.9	.125	.032	−74.4	−79
11	10	Sec. 32, T. 19 N., R. 3 W.	[3] 3.05	.0593	.0142	3.06	1.31	468	52.0	17.0	.039	.013	−66.6	−72
12	11	Sec. 18, T. 18 N., R. 3 W.	[4] 3.03	.0917	.0128	5.60	2.90	1,000	111	36.6	.140	.056	−60.0	--------
13	12	Sec. 17, T. 18 N., R. 3 W.	[5] 7.33	.0747	.0083	8.60	3.67	2,180	242	33.0	.131	.047	−64.0	--------
14	13	Sec. 3, T. 18 N., R. 3 W.	.33	.0814	.0232	.98	.53	132	14.7	44.5	.090	.196	+118	--------
15	Chico Arroyo near Guadalupe.	Sec. 30, T. 16 N., R. 3 W.	1,390	.0540	.0044	50.2	15.3	188,600	20,960	15.1	.042	.032	−23.8	−62
	Agr. Research Service Albuquerque watersheds:													
16	W-I	Sec. 22, T. 10 N., R. 3 W.	.15	.1650	.0269	.73	.38	34.8	3.9	25.8	.096	.120	+25.0	0
17	W-II	Sec. 14, T. 11 N., R. 2 W.	.06	.1383	.0421	.48	.22	26.2	2.9	48.5	.255	.151	−40.8	−67
18	W-III	Sec. 14, T. 11 N., R. 2 W.	.33	.0693	.0284	.88	.55	73.4	8.2	24.7	.146	.054	−63.0	−80
19	San Jose River at Correo	Sec. 31, T. 9 N., R. 3 W.	[6] 2,395	.0530	.0035	90.2	38.8	105,260	11,700	4.9	--------	--------	--------	−92
20	Rio Puerco at Rio Puerco	Sec. 31, T. 7 N., R. 1 W.	[6] 4,945	.0610	.0026	118.9	54.7	399,780	44,420	9.0	.033	.025	−26.7	−65
21	Rio Puerco at Bernardo	Sec. 8, T. 2 N., R. 1 E.	[6] 5,645	.0600	.0022	151.5	89.2	388,000	43,110	7.6	--------	--------	--------	--------
22	Rio Salado near San Acacio.	Sec. 30, T. 1 N., R. 1 E.	1,380	.0630	.0057	74.0	30.6	98,360	10,930	7.9	.025	.012	−52.0	−84

[1] Includes Cornfield Wash watershed 17.
[2] Includes Cornfield Wash watershed 16.
[3] Includes Cornfield Wash watershed 10.
[4] Includes Cornfield Wash watersheds 18, 19, and 21.
[5] Includes Cornfield Wash watershed 20.
[6] Drainage area reduced by 215 sq mi; controlled by Bluewater-Toltec Reservoir.

that the watershed is composed mainly of rough broken badlands, which is unusual.

The runoff-rainfall relation is usually curvilinear; therefore, a direct comparison of runoff to precipitation should be avoided. If a series of wet years is followed by a series of dry years, a significant change in the runoff-rainfall ratio should occur. A study was made to test the possibility that the reduction in the runoff-rainfall ratio for the watersheds in and near the Cornfield Wash basin was due to the curvilinear nature of the relation. The method used is the same as that used by Oltman and Tracy (1951). Summarized briefly, the procedure is as follows: (1) Prepare a curve showing the average relation between seasonal rainfall and runoff, (2) list the synthetic runoff values taken from the curve, and (3) study the consistency of the synthetic and measured runoff by a double-mass curve.

The method used by Oltman and Tracy (1951) is illustrated by a study of the seasonal runoff data for the gaging station at the Rio Puerco at Rio Puerco. The relation of seasonal runoff (May to October) to seasonal precipitation is shown in figure 19. The seasonal rainfall is from the records at Laguna (pl. 1). The coefficient of correlation is 0.77, and the standard error of estimate is 0.26 log unit. The double-mass relation of computed runoff to measured runoff is shown in figure 20.

Except for watershed W–I near Albuquerque and Cornfield Wash watershed 13, the double-mass relation shows a reduced ratio of measured runoff to synthetic runoff for all watersheds. The magnitude of the change (table 13) is computed by the equation:

$$\text{Percent change}=100\left(\frac{R_b-R_c}{R_b}\right),$$

where

R_b=slope of the double-mass curve relating measured runoff to synthetic runoff before 1957; and
R_c=slope of the double-mass curve relating measured runoff to synthetic runoff after 1957.

There are many possible explanations for the inconsistency that is indicated by relations of computed runoff to measured runoff. Unfortunately, a double-mass analysis does not indicates what causes an inconsistency; the reason for the inconsistency in data, therefore, must be found by other means (Searcy and Hardison, 1960). As a reduced ratio of measured runoff to computed runoff was noted for all watersheds except the two previously mentioned, two logical

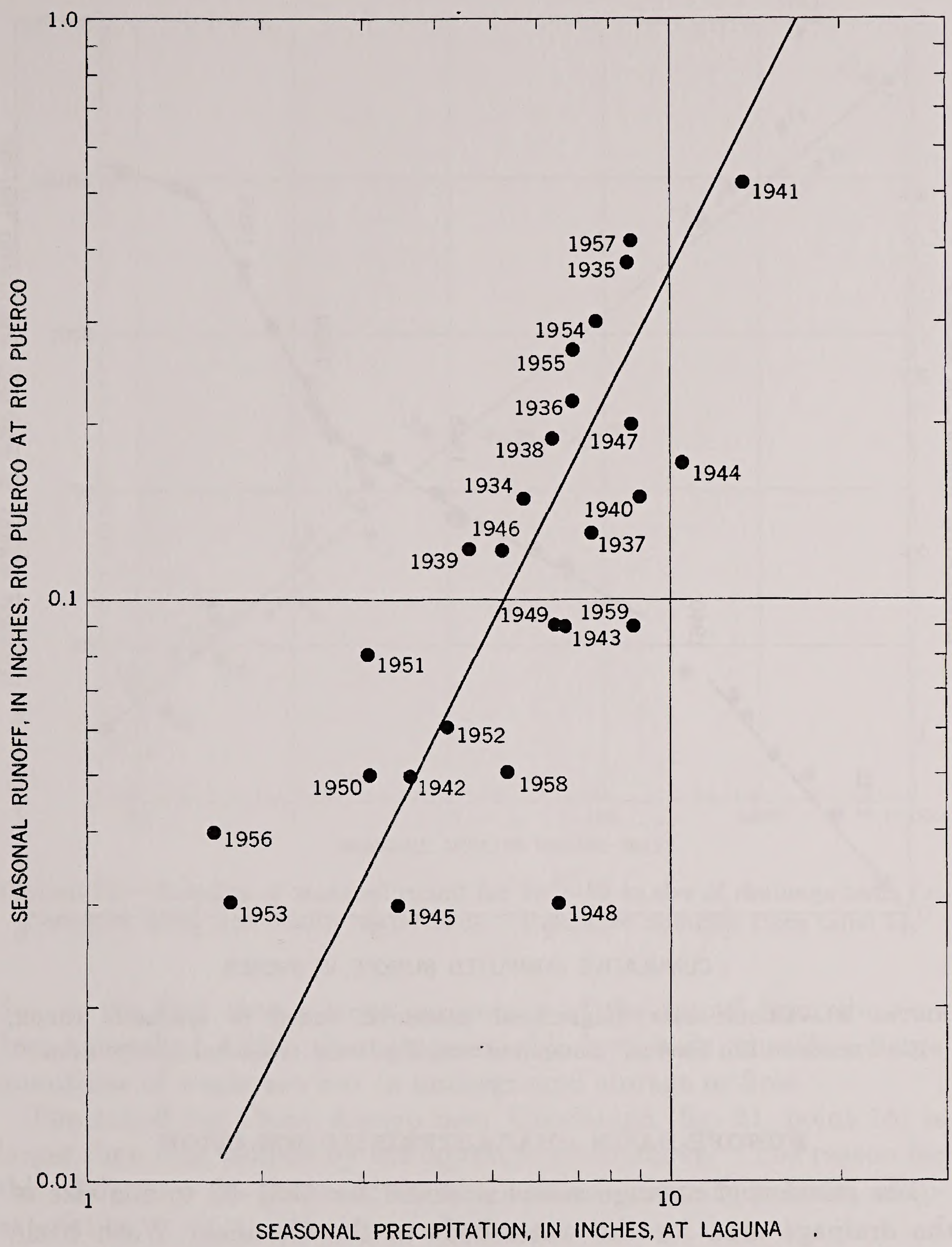

FIGURE 19.—Relation of seasonal runoff to seasonal precipitation, Rio Puerco at Rio Puerco (1934–59).

reasons for the inconsistency are (1) the effects of increased vegetation as a result of the "wet" year of 1957, or (2) the effects of decreased rainfall intensity. Both resulted in a decrease in the ratio of runoff to rainfall, but the major part of the reduction probably is caused by the decrease in the rainfall intensity.

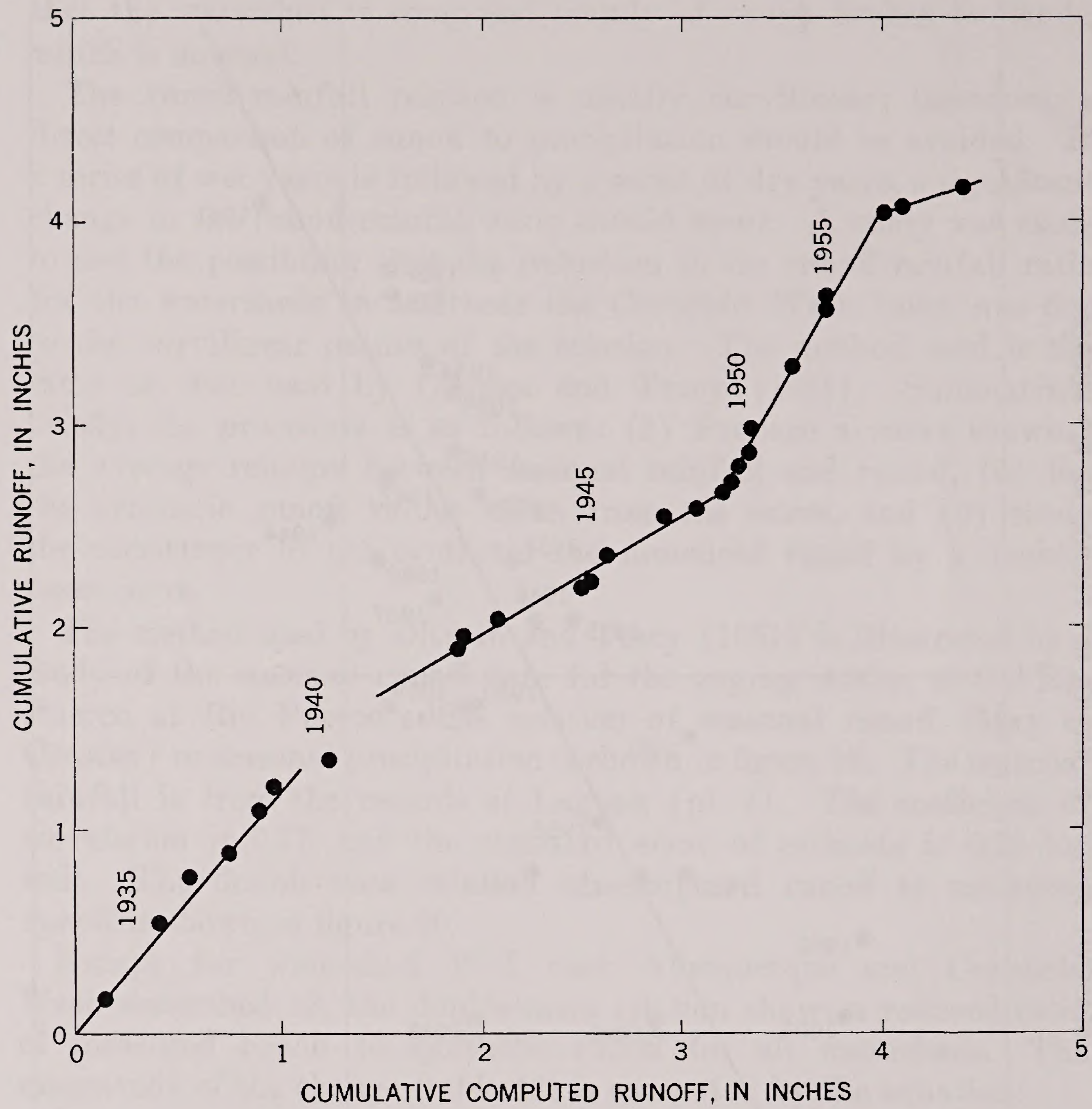

FIGURE 20.—Double-mass diagram of measured runoff to synthetic runoff, Rio Puerco at Rio Puerco. Computed runoff=0.0038 (seasonal precipitation)^2.

RUNOFF-BASIN CHARACTERISTIC RELATION

The relation of average seasonal runoff for 1951–59 to the size of the drainage area for the watersheds in the Cornfield Wash basin and other nearby basins is shown in figure 21. The equation of the line drawn through the points is:

$$R = 29.4(A_d)^{0.82}.$$

The standard error of estimate is 0.168 log unit, and the coefficient of correlation is 0.99.

The runoff from Rio San Jose at Correo (fig. 21, point 19) is much smaller than that defined by the equation given above. This may be

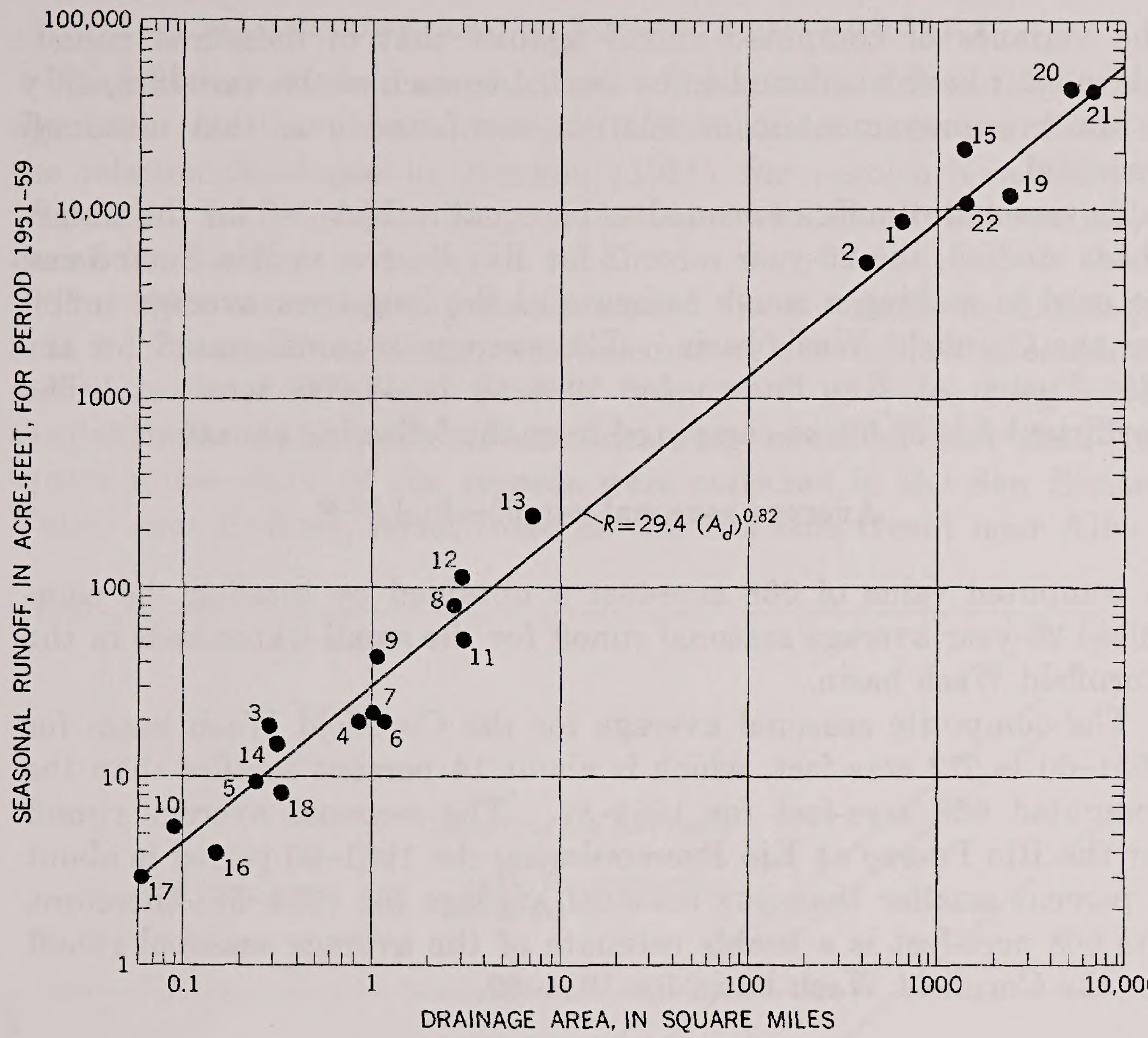

FIGURE 21.—Relation of seasonal runoff for 1951–59 to size of drainage basin for Cornfield Wash and nearby watersheds. Reference numbers from table 13.

due to the fact that a large percentage of the runoff from the San Jose watershed drains through permeable lava beds; therefore, large quantities of water are lost to underground storage or flow.

The runoff for Chico Arroyo near Guadalupe (fig. 21, point 15) is larger than that defined by the equation given above. The reason for this difference is discussed in the section comparing basin characteristics.

Studies in which total seasonal runoff was related to the size of the drainage basin were made using records for 1951–55 and 1956–59. For both periods of study, R was proportional to $(A_d)^{0.82}$. Therefore, it is concluded that for the watersheds studied, total seasonal runoff, in acre-feet, and average seasonal runoff, in acre-feet per year, are proportional to $(A_d)^{0.82}$. Also, the average seasonal runoff, in acre-feet per square mile per year, is equal to $k(A_d)^{-0.18}$. The coefficient k is controlled mainly by the climatic condition during the study.

Other drainage-basin characteristics, such as L, L_{ca}, S_L, and S_{st}, were used in a multiple-correlation analysis in an attempt to reduce

the variance of computed runoff against that of measured runoff. Although runoff was found to be related to each of the variables, only a minor improvement in correlation was found over that of runoff versus A_d.

As seasonal runoff is assumed to be equal to $k(A_d)^{0.82}$ for the watersheds studied, the 26-year records for Rio Puerco at Rio Puerco can be used in making a rough estimate of the long-term average runoff for the Cornfield Wash basin. The average seasonal runoff for the Rio Puerco at Rio Puerco for 1934–59 is 44,000 acre-feet. The coefficient k is 37.60, as computed from the following equation:

$$\text{Average seasonal runoff} = k(A_d)^{0.82}.$$

A computed value of 668 acre-feet is obtained by totaling the computed 26-year average seasonal runoff for the small watersheds in the Cornfield Wash basin.

The composite seasonal average for the Cornfield Wash basin for 1951–60 is 572 acre-feet, which is about 14 percent smaller than the computed 668 acre-feet for 1934–59. The seasonal average runoff for the Rio Puerco at Rio Puerco during the 1951–60 period is about 7 percent smaller than the seasonal average for 1934–59; therefore, the 668 acre-feet is a usable estimate of the average seasonal runoff for the Cornfield Wash basin for 1934–59.

TRANSIT LOSSES

It is not known why unit runoff decreases with the size of the basin, but it is assumed to be due to either precipitation or transit losses. Sufficient data are not available to determine which is the more influential in causing the decrease; nevertheless, the following discussion is given.

It has been shown that the average precipitation near Cornfield Wash decreased with the decrease in altitude (fig. 18), but in the nonmountainous areas the reduction is small for relatively large areas. Also, it is recognized that the precipitation comes predominantly from thunderstorms, one of which may center over a particular small basin. However, if a long period of time is considered, the number of thunderstorms per unit of area should not be any greater for a small basin than for a nearby large basin. Therefore, the variation in precipitation probably is not the primary reason that the unit runoff decreases with the increase in basin size, but, instead, the decrease is largely due to transit losses. The transit losses are magnified because the precipitation comes predominantly from localized thunderstorms.

MAGNITUDE AND FREQUENCY OF RUNOFF

The relation of mean annual flood volume to the size of the drainage basin for the Cornfield Wash area indicates more runoff than the relation developed by Kennon (1954) for western New Mexico (fig. 22). In his study, Kennon (1954) included all the available runoff in that area to 1952.

The 1952 curve relating mean annual flood volume to drainage area in western New Mexico was based on relatively few streamflow records. Only 14 of the records from 5 to 12 years long were available for ephemeral streams draining areas of less than 10 square miles—four of the records were collected in the San Simon Valley near Safford, Ariz., three on the Montano Grant near Albu-

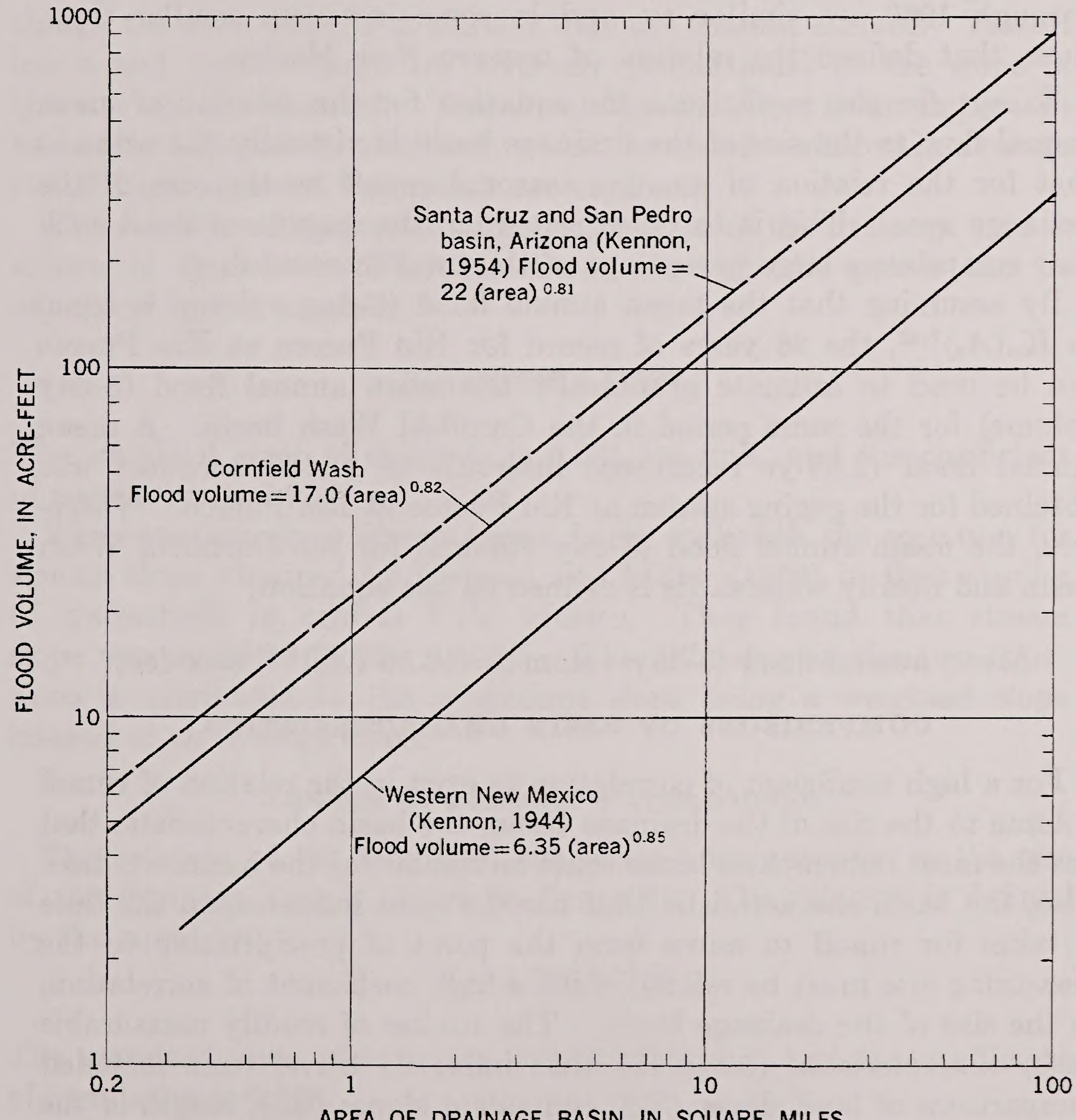

FIGURE 22.—Relation between mean annual flood (3-day volume) and size of drainage basin.

querque, two near Santa Fe, and five at Mexican Spring near Gallup, N. Mex. Therefore, it is not surprising that the mean annual flood volume at Cornfield Wash differs from the average computed from the meager records available in 1952. The main difference in the relation as concluded from the Cornfield Wash data against the relation for western New Mexico is attributed to different periods of record. The seasonal variation in climate is so great that 5 or 10 years of runoff records are not of sufficient length to define graphically the mean annual flood. For example, the mean annual floods for Cornfield Wash from 1951 through 1955 plotted in a manner similar to those in the relation for the San Pedro and Santa Cruz River basins in southern Arizona (Kennon, 1954, fig 5); whereas, the mean annual floods for Cornfield Wash from 1956 through 1960 are similar to, and in some instances smaller than, those that defined the relation of western New Mexico.

Except for the coefficients, the equation for the relation of mean annual flow to the size of the drainage basin is virtually the same as that for the relation of average seasonal runoff to the size of the drainage area. This is to be expected, as the maximum flood each year comprises a large percentage of the total seasonal flow.

By assuming that the mean annual flood (3-day volume is equal to $K_m(A_d)^{0.82}$, the 26 years of record for Rio Puerco at Rio Puerco can be used to estimate graphically the mean annual flood (3-day volume) for the same period in the Cornfield Wash basin. A mean annual flood (2.33-yr recurrence interval) of 11,400 acre-feet was obtained for the gaging station at Rio Puerco at Rio Puerco. Therefore, the mean annual flood (3-day volume) for the Cornfield Wash basin and nearby watersheds is defined by the equation:

$$\text{Mean annual flood (3-day volume)} = 10.36\ (A_d)^{0.82}\ \text{acre-feet.}$$

COMPARISONS OF BASIN CHARACTERISTICS

For a high coefficient of correlation to exist in the relation of runoff volume to the size of the drainage basin, the basin characteristic that has the most influence on losses must be similar for the basins studied. Also, the basin characteristic that has the most influence on the time it takes for runoff to move from the point of precipitation to the measuring site must be related, with a high coefficient of correlation, to the size of the drainage basin. The studies of readily measurable basin characteristics (table 13) that influence travel time included comparisons of land slopes (S_L), equivalent slopes (S_{st}), length of the longest watercourse (L), and distance along the longest watercourse from the gaging site to a point opposite the center of the drainage area (L_{ca}).

LAND SLOPE

The first comparison was that of the size of the drainage area versus land slope (fig. 23). The relation of land slope to the size of the drainage area is defined by the equation:

$$S_L = 0.775(A_d)^{-0.035}.$$

The standard error of estimate is 0.12 log unit, and the coefficient of correlation is 0.36. The poor correlation indicates that the size of the drainage area is not a very good indicator of the land slope, especially for small watersheds.

EQUIVALENT SLOPE

The amount of loss in a natural channel varies with, among other things, the time water is in contact with the channel surface. Transit losses and contact time are inversely proportional to the slope of the conveyance channel. Therefore, channel slope is an important basin characteristic in studies in which causes of variation in average runoff from adjacent watersheds are explored.

The relation of equivalent slope to the size of the drainage area is shown in figure 24. The line drawn through the points can be expressed by the equation:

$$S_{st} = 0.022(A_d)^{-0.23}.$$

The standard error of estimate is 0.031 log unit, and the coefficient of correlation is 0.987.

The equation given above agrees fairly well with the equation for stream slope obtained by Leopold and Miller (1956) in their studies of watersheds in central New Mexico. They found that stream slope was equal to 0.022 $(A_d)^{-0.18}$. The difference in the two equations is attributed to the equivalent slope being a weighted slope instead of an average slope.

LENGTH OF LONGEST WATERCOURSE

The relation of the length of the longest watercourse to the size of the drainage area is shown in figure 25. The relation is defined by the equation:

$$L = 1.72(A_d)^{0.52}.$$

The standard error of estimate is 0.133 log unit, and the coefficient of correlation is 0.988.

The equation of the relation of the longest watercourse to the size of the drainage area in the Cornfield Wash studies agrees very well with a similar equation developed by Leopold and Miller (1956).

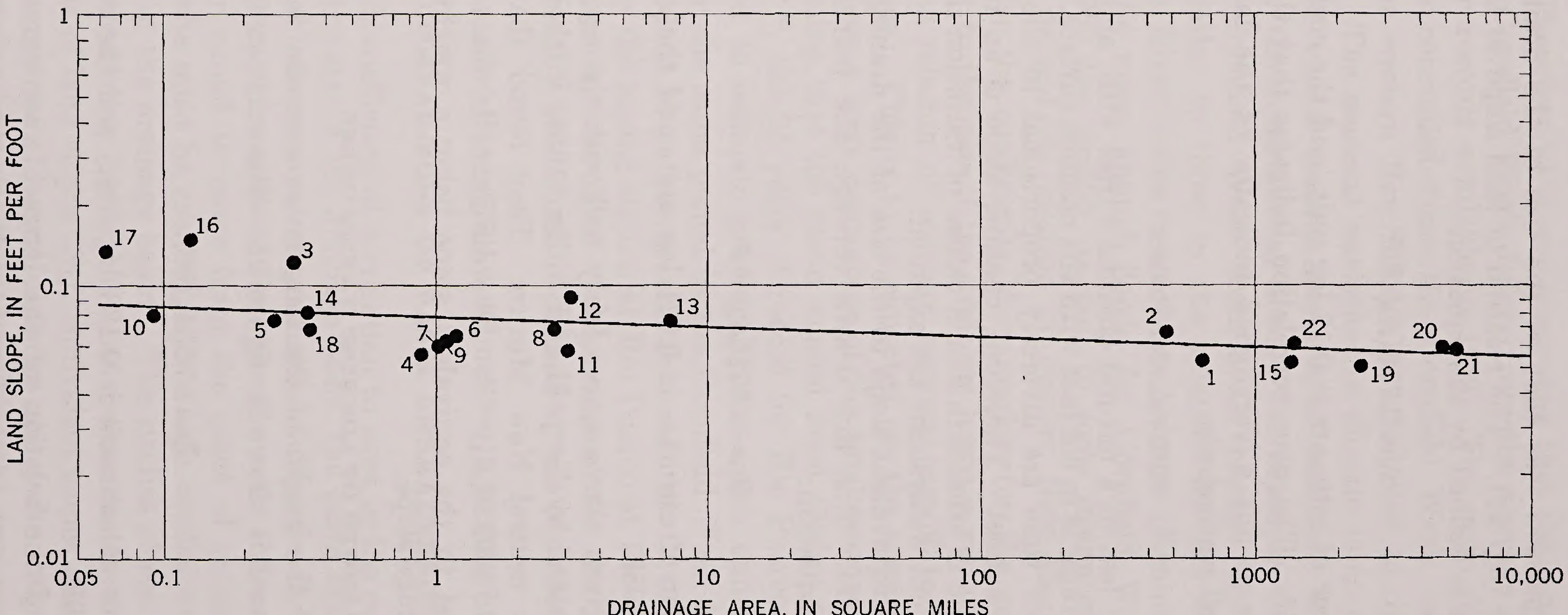

Figure 23.—Relation of land slope to size of drainage basin. Reference numbers from table 13.

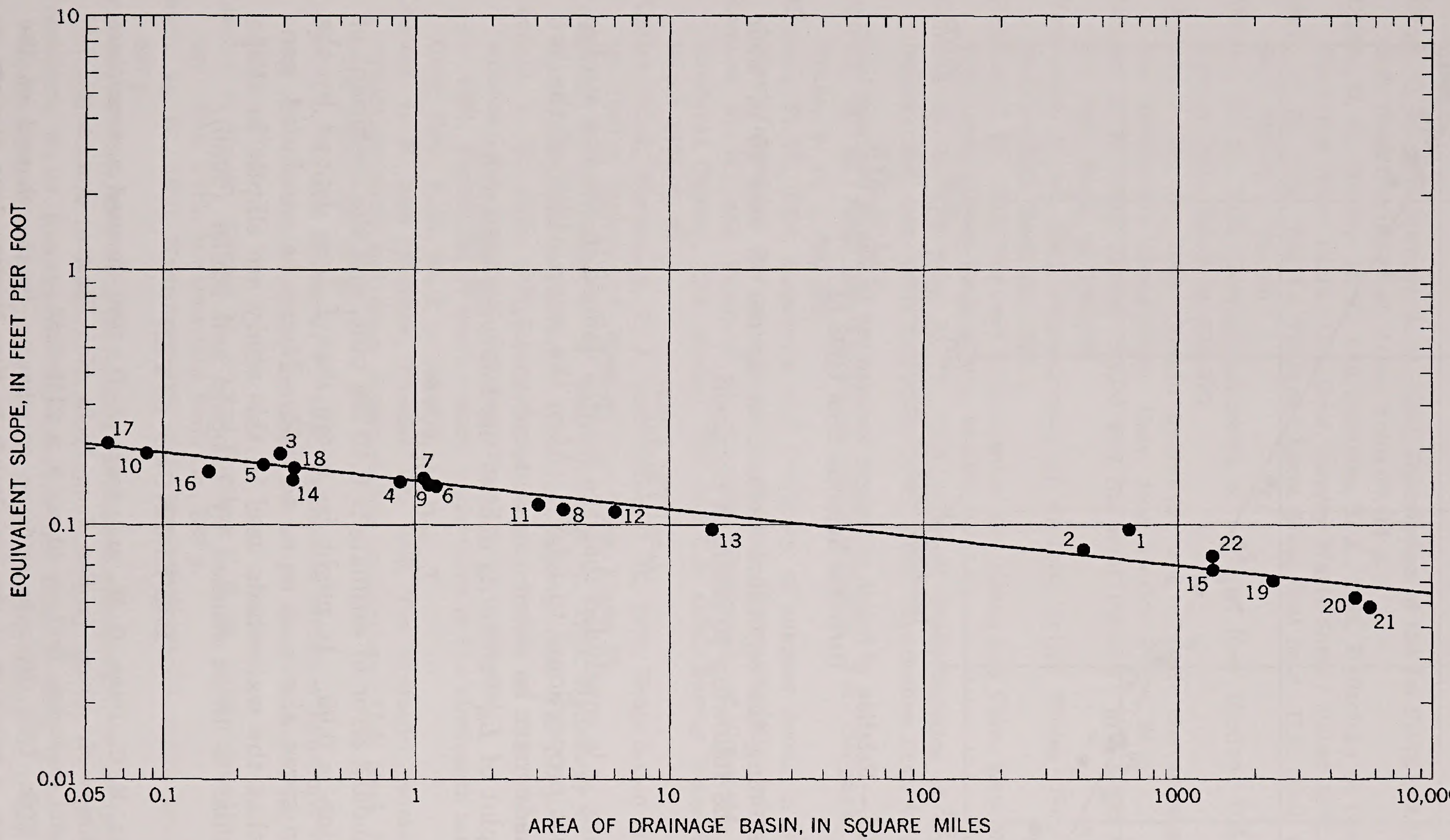

Figure 24.—Relation of equivalent slope to size of drainage basin. Reference numbers from table 13. Numbers 8, 12, and 13 include drainage tributary to upstream reservoirs.

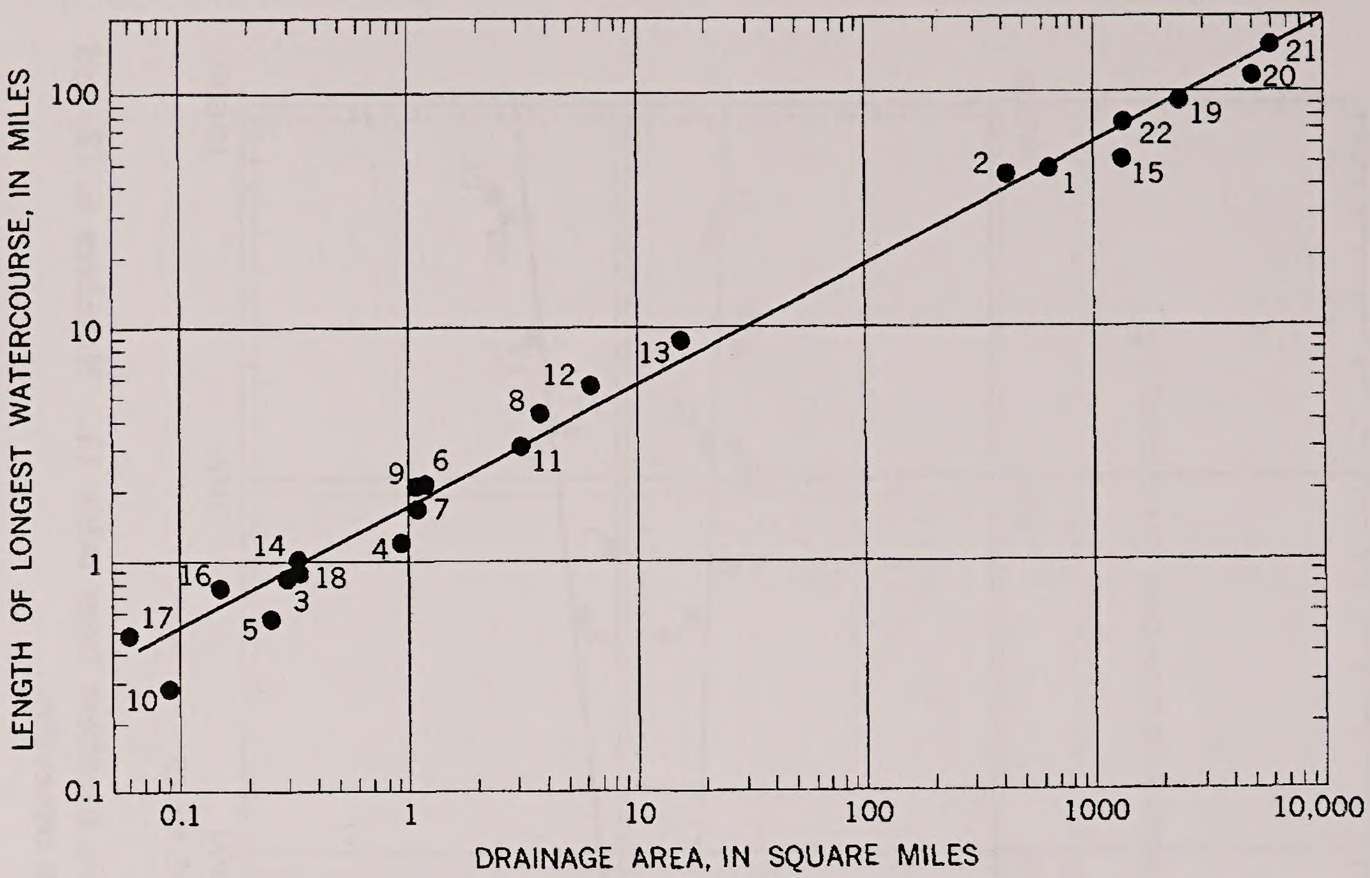

FIGURE 25.—Relation of length of longest watercourse to size of drainage basin. Reference numbers from table 13.

By combining the equations defined in figures 13 and 16 of their report, the following equation is obtained:

$$L=1.72(A_d)^{0.54}.$$

Therefore, it is concluded that the lengths defined in the two studies are about proportional to $(A_d)^{0.5}$. Also, the mean width of the two watersheds must be about proportional to $(A_d)^{0.5}$.

The plot of L_{ca} versus A_d defines the following equation:

$$L_{ca}=0.86(A_d)^{0.52}.$$

The standard error of estimate is 0.10 log unit, and the coefficient of correlation is 0.99. It might be noted that L_{ca}, as defined by the equation given above, is equal to 0.56. It can be concluded, generally, that the watersheds used in this study are elliptic in shape and similar to those studied by Leopold and Miller (1956).

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